Foundation

Potentially polluting wrecks: protecting people and planet

Insights from the Project Tangaroa coalition

August 2025

Lloyd's Register Foundation

About Project Tangaroa

Project Tangaroa is a Lloyd's Register Foundation-funded programme delivered by Waves Group and The Ocean Foundation, as part of the *Threats to Our Ocean Heritage* grant. It is supported by the International Union for the Conservation of Nature (IUCN) and the International Committee on the Underwater Cultural Heritage (ICUCH), a scientific committee of the International Council on Monuments and Sites (ICOMOS). It was initiated to develop a global framework for the near- and long-term assessment, intervention and sharing of data on potentially polluting wrecks.

Find out more at *project-tangaroa.org*.

About Lloyd's Register Foundation

Lloyd's Register Foundation is an independent global safety charity that supports research, innovation and education to make the world a safer place. Its mission is to use the best evidence and insight to help the global community focus on tackling the world's most pressing safety and risk challenges.

For more information about Lloyd's Register Foundation, visit *lrfoundation.org.uk*.

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Cover photo: Major Projects Foundation

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1 Foreword

The issue of potentially polluting wrecks (PPWs) is one that lies at the intersection of a number of strategic priorities and capabilities for Lloyd's Register Foundation.

Firstly, it is a pressing maritime safety issue – the presence of at least 8,500 legacy war wrecks on the seabed is a navigation hazard as well as a looming pollution risk that threatens lives and livelihoods in coastal communities around the world.

Secondly, it presents an opportunity for the Foundation to apply the wealth of archival information relevant to many of these wrecks that is held by our Heritage Centre – taking our 'learning from the past' approach to a contemporary maritime challenge.

As well as harnessing our heritage assets, this issue has benefited from the Foundation's ways of working to achieve impact – catalytic funding that brings experts and stakeholders together with the aim of bringing about consensus and influencing others to act.

For PPWs, this has been done in partnership with Waves Group and The Ocean Foundation, via the broader Project Tangaroa coalition. We are extremely proud of the expert community this work has created. This insight report is the culmination of that convening; a milestone synthesis of their collective experience, expertise and enthusiasm for tackling this challenge. We are extremely grateful to everyone involved. The report underpins the calls to action of the already-published Malta Manifesto, clearly setting out the current situation and how we must collectively go about addressing the problem.

Fundamentally, we now know what needs to be done – and how to do it – to assess and manage PPWs in a proactive, precautionary way that protects our ocean and the communities who rely upon it, while respecting cultural heritage and the memory of those who gave their lives for their countries at sea.

The challenge – as articulated in the Malta Manifesto – is to marshal the resources and collective will to make it happen at the necessary scale. This requires international standards, a technology roadmap, fit-for-purpose financing mechanisms, local empowerment, and most of all, global leadership and coordination.

It is our hope that, with the support and active involvement of the most relevant UN bodies – UNESCO, the UN Environment Programme and the International Maritime Organization – nation states, industry and funding partners can coalesce around the recommendations of this report and the call to action of the Malta Manifesto, and protect people and planet from catastrophic oil pollution.

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3 The Project Tangaroa workshop programme

In 2023, Lloyd's Register Foundation provided funding to The Ocean Foundation to publish three books on 'Threats to Our Ocean Heritage'. These open access volumes were to cover deep-sea mining, bottom trawling and potentially polluting wrecks (PPWs). Grant funding was also provided to support a partnership between The Ocean Foundation and Waves Group to convene an international community of experts to develop international standards and protocols for PPW assessment and intervention. This grant, and the resulting community of practice, became known as *Project Tangaroa*.

The principal aim was to accelerate a move away from costly and sub-optimal emergency response activity towards a more proactive and strategic approach. The International Union for the Conservation of Nature (IUCN) and the International Committee for the Underwater Cultural Heritage (ICUCH, a scientific committee of the International Council on Monuments and Sites – ICOMOS) were also partners in this work.

Following publication of the volume on bottom trawling, a volume presenting a synthesis of current knowledge on PPW management efforts was published by Springer in 2024:[1]

Threats to Our Ocean Heritage: Potentially Polluting Wrecks
https://doi.org/10.1007/978-3-031-57960-8

Taking this resource as a baseline, a series of international workshops were convened, engaging a wide range of stakeholders to initiate action in the following areas:

- Development of international standards and protocols.
- Identification of options for strategic assessment programmes.
- Production of a technology roadmap to support optimised assessments and interventions.
- Development of a supporting data and archive strategy.

The workshops involved government agencies, regulators, international bodies and foundations, marine industry contractors, finance providers, practitioners and researchers engaged in the PPW domain and those involved in heritage management. These stakeholders were drawn from a broad range of geographies affected by the PPW issue, including Europe, the Americas and the Pacific.

The insights produced directly contributed to the formulation of the Malta Manifesto and this report.

Workshop	Date	Location	Objectives	Attendees
Workshop 1: Governance and Management	4-5 April 2024	London, United Kingdom	Understanding the scope of the problem; who are the 'wreck owners'; the gaps and hurdles; possible solutions.	87
Workshop 2: Technology and Methodologies for Assessment and Intervention	9-11 September 2024	Helsinki, Finland	Identifying environmental risks; oil volume assessments; technology challenges; wreck monitoring and spill responses.	98
South America Online Workshop	15 January 2025	Online	Raising awareness among stakeholders on the coasts of South America, and Mexico.	104
Workshop 3: Data and Archives	4-6 March 2025	Valletta, Malta	Understanding challenges of historic data; data storage; other challenges and barriers. Convening Project Tangaroa stakeholders to collaboratively build key themes and challenges for the Malta Manifesto.	129

The Project Tangaroa partners are very grateful for the support of the workshop hosts, including Dr Juha Flinkman and Tommi Kontto at the Finish Environment Institute and Prof Timmy Gambin and the Heritage Malta team.

The geography of the community of experts and stakeholders convened via these workshops (see figure 1) demonstrated that PPWs are a truly international issue.

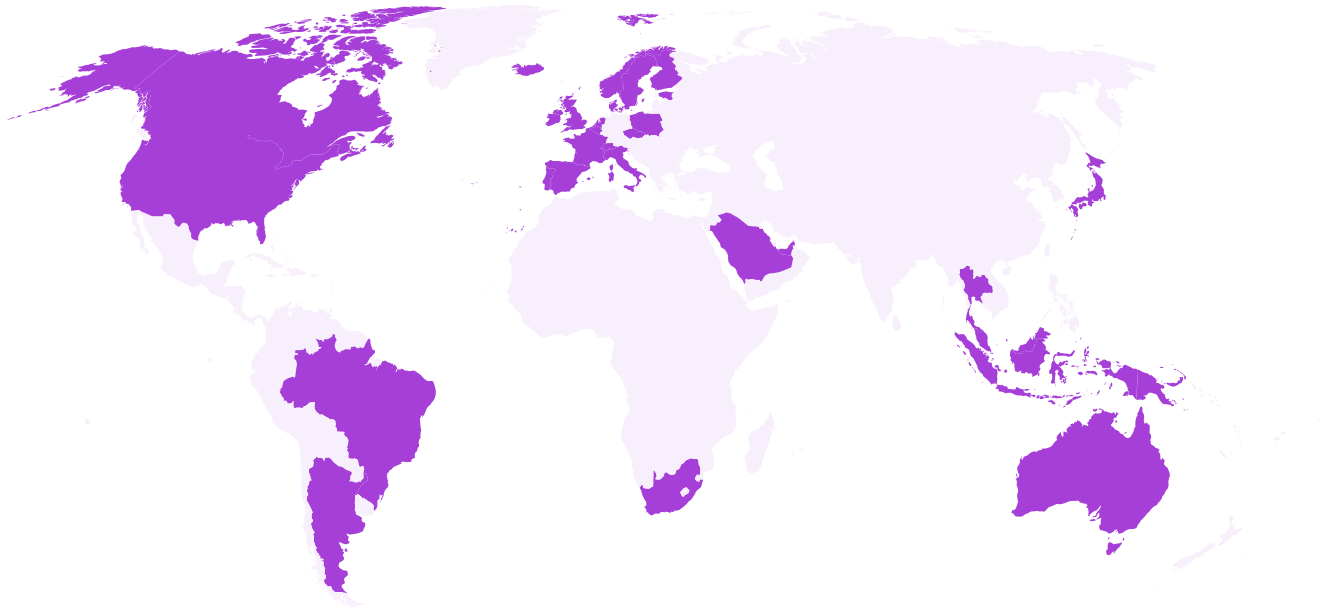

Figure 1: Project Tangaroa workshop attendees, by country.

A word cloud based on the structured workshop discussions (figure 2) shows that, while a large number of issues and challenges need to be addressed, the dominant theme remains a perception of a massive deficit in terms of available resources.

Figure 2: Word cloud of dominant Project Tangaroa workshop themes.

4 The Malta Manifesto

A CALL TO ACTION ON POTENTIALLY POLLUTING WRECKS

OUR SHARED OCEAN. OUR SHARED CHALLENGE.

A global, toxic legacy of shipwrecks containing vast quantities of oil and hazardous materials, including munitions, has been left by two World Wars. We know that these wrecks are deteriorating – a process accelerated by climate change impacts. Many are becoming unstable and unsafe. Some are leaking and causing harm now.

We know that illegal salvage has torn apart hull structures, disturbed cargoes, damaged cultural heritage and released oil. We know that many of these wrecks lie close to vulnerable coastal communities, vital fishing grounds, fragile ecosystems in protected areas and world heritage sites.

We are entering a decade of severely heightened risk of catastrophic damage caused by leaking oil – damage to natural heritage and underwater cultural heritage that cannot be fully remedied. The harm to human wellbeing and the economic cost will be enormous.

The time for concerted, unified action is now. As we approach the 100th anniversary of World War II in 2039, we must commit to resolving this toxic legacy of conflict. People and planet must be protected.

We know how to manage the risk posed by these wrecks. We need urgently to marshal the resources and the collective will to put that knowledge to use – at scale.

OUR VISION.

We envision a world where international cooperation has transformed these environmental and safety hazards into a dynamic inventory of managed sites, where communities and ecosystems vulnerable to these threats are protected through timely assessment, monitoring and intervention.

OUR PRINCIPLES.

1. **A Precautionary Approach:** Prevention Before Crisis: Proactive intervention costs significantly less than an emergency response to catastrophic pollution events.
2. **Global Responsibility, Local Agency:** The challenge demands international coordination with locally led decisions. No nation should face these threats alone. Those most affected should have the strongest voice in finding safe solutions.
3. **Global Expertise, Local Knowledge:** local knowledge, comprehensive data and sound science must guide all actions.
4. **Equitable Burden-Sharing:** Nations that played no role in creating this crisis face some of the most severe threats. All stakeholders should contribute to solutions. Financial constraints must not prevent action.
5. **Sustainable Solutions:** Long-term management systems must outlast any single initiative or funding cycle.

OUR CALL TO ACTION.

We call upon governments, industry, the research community and civil society to unite in addressing this challenge through these critical pathways:

1

ADVOCACY

Potentially Polluting Wrecks (PPWs) can be safety hazards and at the same time support local biodiversity. They can have significant heritage value and many still contain human remains. Some are considered as war graves. We call for policy solutions at national and international levels that both address this complex reality and assure timely action.

2

INTERNATIONAL COLLABORATION AND STANDARDS

We call for the support of nations and international agencies for the development and adoption of globally recognized assessment protocols and intervention standards that enable necessary action even in disputed areas, and waters beyond national jurisdiction.

3

RESILIENCE AND RESPONSE CAPACITY

We call for the inclusion of PPWs in regional and national planning for resilience and response to oil spills in order to assure maximum permitted use of existing programmes, policy frameworks and resources alongside development of new protocols and capacity.

4

EMPOWERMENT

We call for awareness raising and provision of training, tailored to local needs and circumstances, to enable communities to shape management efforts and participate safely in response activity.

5 FINANCING AND INVESTMENT IN OCEAN HEALTH

International cooperation is central to paying for the management of PPWs. We therefore call for the creation of a PPW Finance Task Force to ensure resources are committed at a level that matches the scale and urgency of the crisis. The Task Force would deliver diversified funding mechanisms by:

- catalysing the creation of targeted multi-lateral finance instruments;
- championing innovative solutions that leverage private sector resources alongside philanthropy;
- advocating for provision for PPW management in standardised due diligence and risk-mitigation processes that safeguard investments in our ocean via mechanisms such as Marine Protected Areas, Blue Bonds and Habitat Restoration projects.

6 INCREASE ACCESS TO TECHNOLOGICAL INNOVATION AND SURVEY PLATFORMS

We call for large-scale access to cost-effective and easily deployable technology for gathering baseline data, assessment monitoring and remediation. We call for collaboration with Research Vessel operators and others to increase data acquisition opportunities. We call for intense collaboration with industry and research sectors to enhance existing capabilities, lead the necessary technology acceleration and democratise solutions.

7 INCREASE ACCESS TO DATA

We call for the widest possible sharing of data and archive material to establish baseline information, enable assessment of vulnerability and increase assurance that appropriate management options will be selected through locally informed, evidence-led decision making.

THE COST OF FAILING TO ACT DECISIVELY

If we do not act with urgency and ambition, the inevitable costs are multifaceted and severe:

- Destruction of coastal livelihoods, fishing grounds and other food sources leading to long-term hardship and reduced resilience.
- Destruction of tourism with deeply damaging impacts on local employment and national economies.
- Disproportionate impacts on vulnerable coastal communities with limited emergency response capacity.
- Contamination of sensitive ecosystems and marine protected areas causing profound harm to biodiversity and the health of our oceans.
- Toxic leakage into marine food chains with broad human health implications.
- Increased costs for clean-up and severe health risks to people involved in clean-up operations where training and safety equipment is inadequate.
- International disputes over responsibility and reparations, complicating diplomatic relations.

WE KNOW HOW TO AVOID THESE DEVASTATING OUTCOMES.

COMMITMENT TO ACTION.

Join us in committing to build upon the knowledge and expertise already highlighted by Project Tangaroa; to lead and inspire, marshalling the resources required to put that knowledge to use at scale and to make substantial progress towards comprehensive, global, PPW management by 2039.

By acting now we can avoid immense harm to people and to nature. We can honour our obligation to heal historical environmental wounds and our responsibility to future generations, who deserve safe and healthy oceans – free from the toxic legacies of past conflicts.

5 PPWs: frequently asked questions

What are 'potentially polluting wrecks'?

A potentially polluting wreck (PPW) is a shipwreck containing a cargo of oil and/or its own fuel oil that has the potential to cause environmental damage and disrupt maritime systems if it leaks or there is a catastrophic release. Many PPWs are casualties of the First and Second World Wars and, as war wrecks, pose particular challenges that need to be addressed.

PPWs can be safety hazards yet at the same time support local biodiversity. They can have significant heritage value, and many still contain human remains. Some are considered to be war graves. There is a need for policy solutions at national and international levels that both address this complex reality and assure timely action.

While Project Tangaroa is concerned with oil, there are other types of pollutants which can be trapped on shipwrecks. These include unexploded ordnance and munitions, and the toxic and carcinogenic compounds they can leak. The issue of munitions (from dumps as well as shipwrecks) is being covered by the Remediation, Management, Monitoring and Cooperation addressing North Sea unexploded ordnance (REMARCO) project.[2] Tangaroa and REMARCO cooperate closely and will work together to develop protocols for dealing with the toxic legacy of war.

How many potentially polluting wrecks are there?

Since a widely-cited PPW study in 2005, it has been generally accepted that there are **more than 8,500 PPWs** which are either tankers larger than 150 gross tons or non-tanker vessels larger than 400 gross tons.[3] However, the study authors themselves note, because they did not include smaller vessels, the actual scale of the environmental hazard may be much greater, particularly at the local level.

The figure of around 8,500 PPWs in the 2005 study is considered to be an indicator of the scale of the PPW challenge. However, the study itself acknowledged that this may be an underestimate, saying: "there is considerable evidence that there is a much larger set of wrecks of smaller vessels that, while holding less oil, could present significant environmental hazards on a localised level." That said, it appears very likely that the dataset captured the vast majority of the largest vessels, particularly tankers, which hold the greatest amount of oil. Experts who participated in the three Project Tangaroa workshops endorsed the view that the 8,500 figure is likely to be an underestimate.

Other studies have also highlighted the potential importance of smaller, often poorly documented vessels – specifically those under 100 gross tons. These are often excluded from risk assessments due to their perceived limited capacity for polluting materials. However, even small leaks from vessels in shallow water near sensitive sites can have significant impacts. The aggregation of shipwrecks, particularly concentrations of these smaller vessels, may pose a significant regional pollution risk. Aggregated risk from multiple smaller vessels is also a primary concern for aquaculture sites.[4]

The 8,500 figure relies heavily on documentary sources. Many of the wrecks identified as pollutant threats have not been discovered or assessed yet. Some of these wrecks may not actually be a risk, others may pose far greater risks than expected.

Where are potentially polluting wrecks located?

This is a global problem. The South Asian-Pacific region has the highest concentration of PPWs due to the fierce naval battles in the Pacific Theatre of the Second World War. In the Mediterranean and the Arctic, many vessels lost from wartime convoys lie on the seabed. Even in areas that did not see major battles, such as the Caribbean and the South Atlantic, concentrations of PPWs exist as a result of blockades. In the North Sea and Baltic Sea regions, PPWs and other polluting legacies of war pose a growing threat.

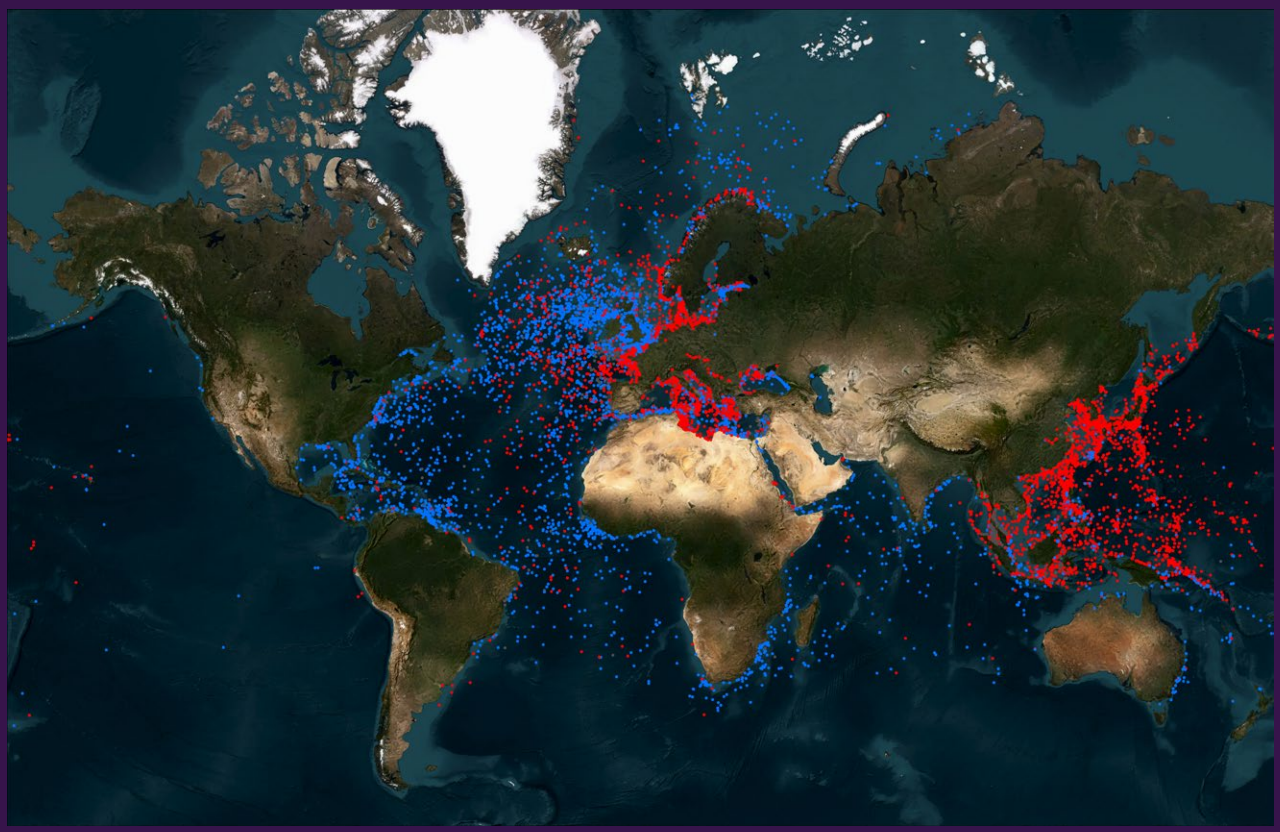

Figure 3: 'Sunken Ships of the Second World War' database by Paul Heersink. Blue dots represent Allied ships; red dots are Axis.

The South-Asian Pacific region has the highest estimated percentage of known tanker vessels and a large percentage of the worldwide estimate of oil remaining within wrecks. The Blue Pacific is also one of the most vulnerable environments to even small amounts of leaking oil, as the "health of the ocean is fundamental to the sustainability of all aspects of island life".[5] The second highest region of PPW concentration, when it comes to tank vessels, is also in the Pacific: the northwest. Here, more than 15% of known tankers, with 5% of the global oil total, is encased in the fragile hulls of the legacy wrecks.

War wrecks pose growing threats in the Baltic and North Sea regions. The Baltic is a vulnerable inland sea with a low capacity to self-purify and flush pollutants from the system. It saw high volumes of ship traffic during both World Wars, and a mix of merchant and naval wrecks remain,[6] as well as other vessels sunk in storms or collisions. For example, in 1945's Operation Hannibal alone, roughly 250 vessels sunk, many carrying fuel. In the North Sea, there are thousands of ship and aircraft wrecks,[7] mostly sunk in sea battles during the World Wars or scuttled during post-war dumping activities.

The North Atlantic Ocean has an estimated quarter of the world's PPWs, with a high volume of oil within them. The German U-boat campaign during the Battle of the Atlantic, for example, sunk some 3,500 merchant ships.

The Mediterranean has a smaller percentage of vessels and oil, but considering its size and fragile environment, the number is concerning. The DEEPP (Development of European Guidelines for Potentially Polluting Shipwrecks) project attempted to record these vessels in one area and found that only a quarter of the wrecks were previously known.[8]

The Arctic Ocean saw millions of tonnes of ship traffic during the First and Second World Wars. In the Second World War in particular, Germany's invasion of Norway and the Soviet Union meant that the Allies needed Arctic convoys to keep these trade routes open. Many ships failed to return from these journeys, as they were targeted by German warships. In the South Atlantic, Allied economic blockades also resulted in many casualties.

What damage will oil from potentially polluting wrecks cause?

We know that oil spills cause damage to communities that can be profound and long-lasting, with severe health impacts as well as economic distress. Harm to nature can be catastrophic and widespread. However, the severity of the threat is not simply determined by the total amount oil still contained in PPWs. Risk assessments based on the vulnerability of coastal communities, ecosystems and infrastructure, show that relatively small amounts of oil in the wrong place can have devastating impacts. Additionally, as many PPWs are deteriorating at the same time, the risk of multiple spills in the same region increases.

Many studies have been undertaken on oil spills, such as from the *Exxon Valdez*, examining short and long-term impacts. The harm to communities and nature is profound and enduring.[9] Economic and sociological studies have shown that livelihoods are destroyed and both physical and mental wellbeing are damaged.[10]

For example, psychological stress, including depression and anxiety, affected those reliant on natural resources following the *Exxon Valdez* oil spill and the *Deepwater Horizon* oil spill in the Gulf of Mexico. The psychological stress can lead to heavy alcohol and drug consumption and increased domestic violence.[11] There is clear evidence that women have frequently been particularly badly impacted both economically and in terms of safety when collecting food from affected coastal areas.[12] Further, key sources of employment in coastal areas, such as tourism, are hypersensitive to even small oil spills.[13]

PPW impact modelling has been conducted, but issues such as depth of release, hydrodynamics and weather patterns must all be factored in. The specific impacts can also vary depending on the type of oil released (gasoline, crude oil, diesel, heavy fuel oil, etc.) and the environmental conditions when the spill occurs. However, computational spill modelling is advancing rapidly as a management tool to enhance readiness and spill response planning.[14]

When spills from PPWs occur in remote areas, whether in the Pacific or the Arctic, the impacts may be worse and assistance harder to provide.

Why are we in a critical period for potentially polluting wrecks?

PPWs from the World Wars have experienced decades of corrosion – that alone would be enough to raise concerns about the integrity of their hull structures and the risk of catastrophic oil release. However, this deterioration is now being accelerated by climate change impacts that increase corrosion and place even greater stress on already weakened structures. These changes, combined with growing ocean industrialisation, bottom trawling and emerging threats like deep-sea mining, significantly heighten the risks associated with PPWs.

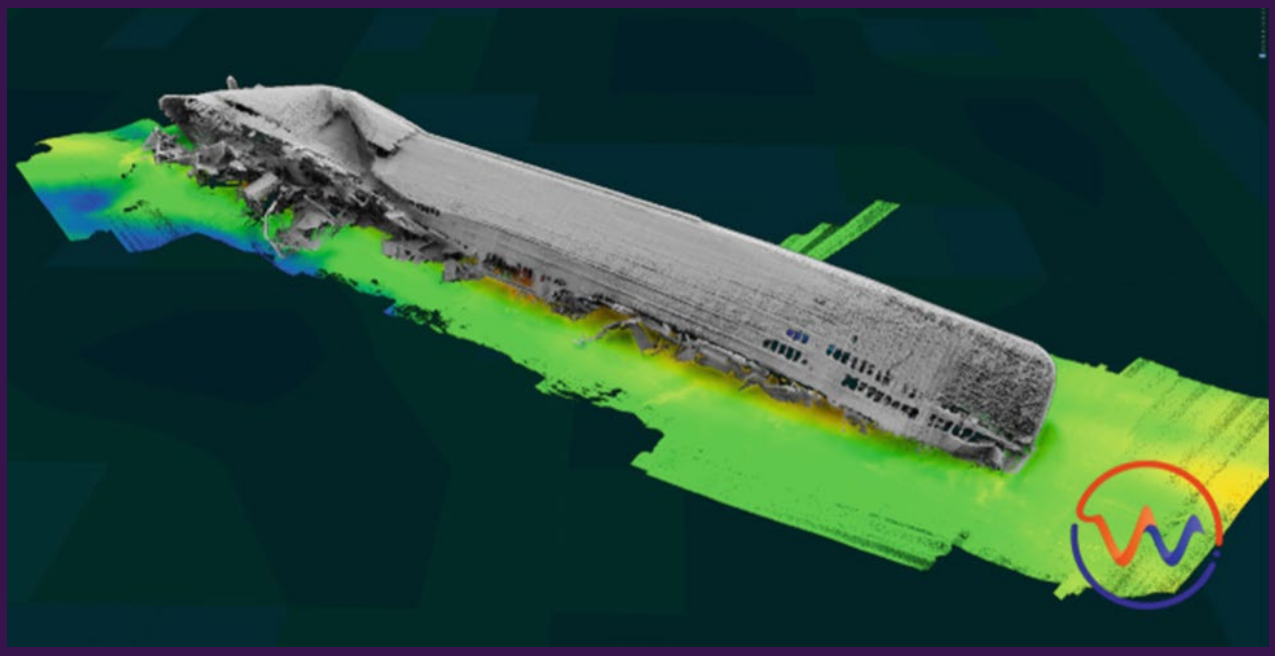

Figure 4: High-resolution multibeam bathymetry data of the wreck of the SS *Derbent*, a World War I tanker (image from Hill et al., 2024)[15].

Three quarters of the estimated PPWs in the ocean are from the Second World War and have been underwater for eighty years – those from the First World War over 100 years.

Research on corrosion rates and potential causes of acceleration of those rates suggests that the risk of a catastrophic release is large.[16] Climate change factors such as warming water temperatures, acidification and increasingly powerful hurricanes, typhoons and storm surges only add to the threat of structural collapse and catastrophic release. Other reasons for concern include observations on how leaks are currently occurring – not through single impacts or a major disturbance event but through a generalised weakening of seams and fastenings that point to decreasing integrity of the hull structure. Increased ocean industrialisation, dredging, and bottom trawling,[17] and new factors like deep-sea mining, all become greater risk factors when the hull structures themselves are becoming less robust.

We have limited detailed information on the condition of the vast majority of PPWs. This in itself is a major problem. However, modern survey methods and advanced digital modelling have been applied to a growing number of wrecks, providing an unprecedented level of detail about the structures and rates of change. The evidence from such surveys is consistent and concerning. For example, in the case of the SS *Derbent*, a First World War tanker, multibeam survey data (figure 4) showed catastrophic collapse over a much shorter time period than previously believed.

Do we know how to remove the oil and dispose of it safely?

Yes. However, standard techniques developed in the marine salvage and oil and gas sectors are relatively expensive. As PPW hull structures become more fragile and dilapidated, it may become much harder to apply some of these standard techniques to achieve controlled removal of residual oil. In addition, remoteness and lack of storage and processing capacity mean that once removed, safe transport and sustainable disposal of waste oil from PPWs can be complex and very costly.

It is not always necessary to remove oil from a PPW – in some situations leaks can be controlled and monitored and surface booms used to manage oil that does escape. However, when a decision is made that removal is the best option, highly effective techniques are available that have been developed through decades of experience in the marine salvage and oil and gas sectors.[18] The industry standard intervention is known as 'hot tapping'.

This involves fixing a plate to the hull structure that allows a hole to be drilled through with minimal leakage of oil. A valve system then allows a hose from the surface to be attached and the oil pumped out. Often, it is necessary to pump steam or heated water into the space containing oil to make it flow. Such techniques have been applied successfully to PPWs.

Like many marine engineering operations, hot tapping is relatively expensive. Large depths, low temperatures and heavy oils can all add operational complexity and safety risks. Particularly with regard to PPWs, the efficiency and effectiveness of such techniques depends heavily on the quality of the information available to assess oil volumes and plan the work. Ideally, archive drawings and engineering reports can be combined with contemporary high-resolution geospatial surveys to optimise operations. For many PPWs, there is little information available and even with such input, intrusive methods – which are potentially problematic – are often used to assess oil location and volume.

It is rarely practical to remove all the oil from a PPW, meaning future leaks remain possible even after hot tapping. Strict rules and regulations also govern the transport and disposal of the oil (which can include resale). In many areas where PPWs are a threat, facilities for safe and sustainable disposal of the oil do not exist locally. This can impose significant cost and complexity, especially if transport across jurisdictional boundaries is required.

Why are international standards for potentially polluting wreck management important?

Demonstrating that standards, endorsed by a global community of experts, can be applied to the management of PPWs is a key way of assuring national governments and international bodies that new resources can be made available with a high level of assurance that they will be used effectively and efficiently.

To date, several countries have developed their own methods for PPW risk assessment and management.[19] Unsurprisingly, these reflect particular local conditions and administrative priorities. Other nations can adopt and adapt these methods to suit their own needs and requirements. This validated experience can be used to create a draft framework for the international standards that can be developed through one or more highly respected and recognised agencies, such as the International Maritime Organization (IMO).

In the Baltic Sea region, several countries have developed protocols to assess the risk of marine pollution from PPWs. The Swedish VRAKA methodology is recognised by several other states at the Baltic Marine Environment Protection Commission.[20] The US National Oceanic and Atmospheric Administration (NOAA) RULET method is widely referenced as a tested risk-based approach.[21] The UK E-DBA methodology, commissioned by the UK Ministry of Defence (MoD) and developed by the Centre for Environment, Fisheries and Aquaculture Science (Cefas), goes through a staged approach focusing on environmental impact. However, the E-DBA is just one of the tools used by the MoD to evaluate and prioritise interventions.

While there are similarities and common reference points between these approaches, such as multistage assessment, there are also marked differences in the weight given to different factors. For example, it has been reported that the Finnish approach has moved away from risk assessment to incorporate detailed consideration of the practicality of oil removal in each case.

International standards based on the current best practices are therefore important for classifying PPWs and their associated risks according to potential environmental, social and economic impacts. Having these standards will help governments and other stakeholders know how, where and when to act, and allocate global resources most effectively.

Why are existing oil spill management arrangements not enough? Why are new resources and finance needed?

The PPW threat cannot be managed using existing resources and funding alone. Most current arrangements for oil spill management have been designed to provide emergency response to contemporary incidents that involve privately owned and operated vessels – a scenario that is fundamentally different to the challenge posed by PPWs. Some arrangements explicitly exclude legacy wrecks and casualties of war from their remit.

It is possible that some existing resources can be applied to PPW spills, but this is likely to involve lengthy negotiations about funding. Such delays in mobilisation can turn an oil spill problem into a pollution disaster, especially in remote locations.

The funding model for PPW management should reflect the cooperation needed for dealing with the complex legacy of war. It must also enable proactive intervention and rapid allocation of funds when a catastrophic event is imminent.

There are many domestic and international mechanisms that are designed to deal with oil pollution. Generally, they are for reacting to recent spills from privately owned vessels, as opposed to a preventative or precautionary approach to address threats from legacy wrecks such as those from the World Wars.

A number of international conventions adopted at the IMO since 1969 have imposed liability for oil spills on shipowners and their insurers, as well as establishing the International Oil Pollution Compensation (IOPC) Funds. These funds contribute to covering liability for spills from tankers, and are paid for by tanker cargo interests in each contracting state.

Similarly, the IMO Wreck Removal Convention sets out a clear international framework of obligations, roles, responsibilities and liabilities for the removal of hazardous wrecks. However, all these conventions (and the IOPC Funds) only impose obligations and liabilities for spills that have occurred after these conventions came into force. They do not apply retrospectively and therefore cannot impose liability for events that occurred during the World Wars. Moreover, these conventions apply to private entities and not necessarily to wrecks of state-owned ships.

This and other factors mean PPWs are generally underrepresented in national and regional oil spill contingency planning. They are also not routinely included in risk assessments and due diligence in advance of blue investments[a] and habitat restoration programmes.

a Blue investments, also known as blue finance, are investments focused on the sustainable use and protection of marine and coastal resources, often referred to as the 'blue economy'.

Major operational challenges also exist, and it is important to note that PPW spills would further stress already thinly-spread provision for major spill response. If a problem occurs in connection with planned oil and gas exploration or production, there is rapid access to a mature infrastructure such as shore bases and on-water assets (platform supply vessels, anchor handlers and crew vessels). There will also be a containerised offshore response package – typical elements might include several 3x10ft containers containing offshore booms, power packs, skimmers, temporary storage, dispersant and a delivery system. The ships' crews will have received regular training on the deployment of these systems, and benefit from a multi-million-pound level of investment. When responding to a PPW leak however, these valuable and essential assets are rarely available at short notice and in most circumstances negotiation would be required to establish who will fund acquisition of them or alternatively whether or how costs can be recovered post-deployment.

In terms of overall provision for spill response, existing equipment stockpiles are very few and far between and certainly not available in remote areas (such as the Arctic and the Pacific Islands). Those that are in place are likely to be pre-committed, as with the Maritime and Coastguard Agency stockpile in the UK.

As matters stand, a large-scale spill from a PPW is likely to occur with no prepositioned equipment or agreements in place. The severity of the outcome is therefore inevitable. Even if equipment resources were available, pre-agreed arrangements would have to be in place to allow their deployment, and training of a local workforce would be required to assure occupational safety, maintenance and rehabilitation.

Who owns these potentially polluting wrecks?

Most PPWs originating from the World Wars are sunken state vessels.[b] The flag states of these wrecks, such as the US, Germany, Japan and the UK, have stated that their sunken craft are presumed to remain owned by them, unless expressly abandoned.[22] As such, they are subject to sovereign immunity to avoid the legal enforcement that is generally available against privately owned wrecks.

Sovereign immunity can also help protect PPWs against illegal salvage – sovereign-immune vessels cannot have salvage services conducted upon them without the consent of the flag state. Flag state cooperation is therefore critical in the management of PPWs. Different countries take different approaches to the ownership of their wrecks. The UK MoD, for example, accepts responsibility for management of the pollution risk presented by wrecks and cargos which belonged to them when they sank, wherever they sank.

Under international law, as reflected in the 1982 United Nations Convention on the Law of the Sea (UNCLOS),[23] all nations have a duty to protect our cultural heritage and the natural heritage or marine environment.

b A state vessel is one that is owned or operated by a government, typically for non-commercial purposes.

However, many PPWs from the Second World War sank off the coasts of nations that were not even sovereign states during that war, such as the Republic of the Marshall Islands, the Federated States of Micronesia and the Solomon Islands.

Most of the flag states involved in the Second World War have stated that unless expressly abandoned, the wrecks of their sunken state vessels continue to be owned by them and are therefore subject to sovereign immunity. Moreover, the sovereign immunity asserted here is also found in UNCLOS – including provisions regarding protection of the marine environment – and other international laws such as the 2007 IMO International Convention on the Removal of Wrecks (also known as the Nairobi Wreck Removal Convention).

This arguably implies that flag states claiming property title over such sunken state vessels not only remain the owners of such property, but also have a duty or responsibility to other nations regarding the possible threats to the marine environment they pose. Article 31 of UNCLOS stipulates that the flag state "shall bear international responsibility for any loss or damage to the coastal state resulting from the non-compliance by a warship [...] with the laws and regulations of the coastal state concerning passage through the territorial sea or with the provisions of UNCLOS or other rules of international law".

While flag state's PPWs may be immune from seizure by enforcement authorities, flag states including the US, UK and Japan have cooperated with coastal states on a case by case-by-case basis to address the threat to the marine environment. They will hopefully be willing to cooperate in the future in a way that avoids or minimises pollution and adverse impacts to cultural heritage.

Privately owned tankers and vessels that have been chartered by the flag state in support of their efforts in war may also be subject to sovereign immunity if not on commercial service.

How are they managed now?

Some states have been proactive in conducting risk assessments and other measures to manage PPWs in their own waters – and occasionally in the waters of other nations – although budgets are constrained. However, it remains the case that some nations with a large number of PPWs in their waters do not have the resources to prioritise proactive risk assessments and develop management plans. They often depend on case-by-case negotiation and cooperation with the flag state for reactive assessment and management.

PPWs remain a grave threat to the safety of local lives and livelihoods dependent upon a healthy ocean and coast. Ultimately, international cooperation will be required to deal with the international legacy of war.

There remains a major deficit in resources committed to PPW management and there is no uniform implementation of a precautionary approach. However, it is not true to say that flag states have been inactive – as demonstrated by the examples below.

UNITED STATES

Funded by the US Congress, NOAA conducted a desktop inventory and risk assessment for PPWs in the US Exclusive Economic Zone (EEZ). This included the development of the Risk Assessment Report and RULET database for use by the US Coast Guard,[24] the lead agency addressing oil spills in the US. However, it was completed more than a decade ago, and Congress has not provided additional funding to take the next steps necessary for a preventative or precautionary approach that would avoid or minimise a catastrophic release.

The US Navy has taken a case-by-case approach to its PPWs in foreign waters, but there is no funding or planning for a desktop risk assessment study, much less plans for emergency response or long-term plans for cooperation with foreign nations with US PPWs in their waters. The management of PPWs is thus split between the Coast Guard, the Navy and NOAA.

UNITED KINGDOM

Management of UK Government wrecks is split between the MoD and the Department for Transport. The environmental risk posed by the MoD's inventory of PPWs – comprising approximately 5,700 wrecks around the world, dating from 1870 onwards – is managed by Defence Equipment and Support (DE&S) Salvage and Marine Operations (SALMO). The SALMO Wreck Management team manage this risk on behalf of Navy Command. Wrecks as historical entities are managed by a separate team in Navy Command.

Proactive management of MoD PPWs can be traced to February 1995, when the then-Secretary of State for Defence accepted that the UK MoD had a moral responsibility to intervene on HMS *Royal Oak*, which had started to leak significant amounts of oil into Scapa Flow in the Orkney Islands. This eventually resulted in the MoD taking management responsibility for its wider inventory of PPWs. The MoD policy on wrecks is laid out in JSP 418 Leaflet 10.[25]

JAPAN

Japan, like the US, has undertaken some case-by-case cooperation, such as in the Solomon Islands. However, there appears to be no inventory or risk assessment, much less contingency or long-term planning to avoid or minimise the threat of pollution or harm. Japan has provided funding for a programme regarding recovery of human remains that may be helpful in addressing the threats from Japanese PPWs that also contain them.

GERMANY

Germany was actively involved in the North Sea Wrecks (NSW) project between 2018 and 2023,[26] which spurred the subsequent REMARCO project. NSW involved cooperation between research organisations in Belgium, the Netherlands, Germany, Denmark and Norway, with each country investigating several wrecks within their territorial waters and/or EEZs. The focus was (as with REMARCO) on munitions still onboard the sunken wrecks and their possible impact on the marine environment, and not on residual oil.

6 The big issues

The material in this chapter is drawn from formal presentations and discussions associated with the Project Tangaroa workshop programme. It adds to issues discussed in the *'Threats to Our Ocean Heritage: Potentially Polluting Wrecks'* volume, and highlights matters that need to be considered in planning further work. Expert contributions are presented that provide more depth on key topics and some solutions to specific issues they have encountered that could inform future solutions that could be scaled globally.

6.1 A global challenge that must be understood in regional and local context

Some of the densest concentrations of PPWs are a result of well documented naval battles around the Pacific Islands. Other major theatres of war are also clearly reflected in PPW distribution. A few wrecks have received considerable attention, but the majority have not been accurately located, and those that have are often not adequately monitored. In some regions, such as the North African coast, historical records indicate heavy losses, but relatively little information on PPWs there is currently available.

Regions such as the Caribbean and the South Atlantic, while not the focus of intense conflict, nonetheless contain numerous PPWs as a result of wartime blockades. Here, tankers make up a high proportion of the PPW inventory, so the potential threat level is significant.

Work in the Arctic has highlighted the losses associated with Second World War convoys and PPW management in this region poses new challenges. For example, tracking oil in iced waters is more complex than in other environments and geopolitical tensions mean that relatively little is known about the condition of PPWs in Russian waters.

There is also increasing recognition of the particular set of technical and economic problems posed by deepwater PPWs, a number of which are known in the South Atlantic and Caribbean, while remoteness, whether in the Arctic or Pacific, creates profound operational and logistical challenges.

PPWs are a global threat that defies simple categorisation. The complexity and scale of the problem, spanning many aspects of maritime and marine systems, must be acknowledged. It can seem overwhelming. However, analysis on a regional and local scale can enable practical management options.

FOCUS ON

Brazil and the South Atlantic

Luis Ernesto Arruda Bezerra, Rivelino Martins Cavalcante, Marcelo de Oliveira Soares and Carlos Eduardo Peres Teixeira
Marine Sciences Institute (LABOMAR), Federal University of Ceará

Despite the relatively low military involvement of South America and sub-Saharan Africa in the Second World War, the South Atlantic saw intense military activity. More than 500 wartime wrecks have been reported along the coasts of Brazil and Africa and in international tropical waters – many associated with a blockade mounted by the Allies to limit access to resources by the Axis powers.

In 2018, bales of raw rubber weighing up to 200kg began to appear on the North East coast of Brazil. In 2021 more bales appeared along the coastlines of Brazil, Uruguay and Argentina. The objects represented a severe hazard in their own right – a night-time collision between a dune buggy and a bale reportedly led to the death of two women and the serious injury of a third passenger.

However, areas where the bales appeared were also impacted by the most extensive oil spill ever recorded in the South Atlantic, at the end of 2019.[27] Oil reappeared intermittently in 2020 and 2021 following periods of strong winds, high waves and spring tides. The Bahia and Paraiba states' coastline were re-oiled as late as July 2021. The oil reached more than 55 coastal and marine protected areas including the rich and diverse ecosystem of Abrolhos Marine National Park.

Researchers at the Institute of Marine Science at the Federal University of Ceará (LABOMAR) and the Federal University of Alagoas in Brazil conducted multidisciplinary investigations into the provenance of the bales, including studies of chemical composition and the history of raw rubber shipping from the Far East, as well as the use of an oceanographic particle-tracking model and identification of the colonizing barnacles.[28] [29] This resulted in strong evidence that the bales derived from two different Second World War shipwrecks: the SS *Rio Grande*, lying at 5,762m and the MV *Weserland* which was sunk to a depth of approximately 5,000m with a cargo containing rubber, tin and wolframite. Both lie beyond Brazil's EEZ. Further analysis of the oil involving experts from the Woods Hole Oceanographic Institution (WHOI) in the USA indicated that, across a wide area, the oil exhibited a consistent profile – it could not be tied definitively to these wartime blockade runners but they remain strong candidates as the main source.[30]

While adequate information on the location and condition of wrecks in the region is sadly lacking, investigations have resulted in compelling indications that the rubber, and possibly oil, were released from the wrecks due to illicit salvage efforts; global demand for tin had increased dramatically by 2020 and continued in 2021. Other wrecks with similar cargoes are known to lie in the same waters and it is believed that salvage efforts are continuing, creating new pollution risks.

The threat from legacy wrecks is clearly not confined to oil – the rubber bales represent a physical hazard on the shoreline and fragmentation of the bales will result in release of microplastics. Equally, the complexity of managing such threats in the face of limited coastal state capacity combined with inadequate provision for dealing with pollution emanating from international waters is starkly illustrated.

FOCUS ON

The Arctic Convoys

Giles Richardson
Chief Operating Officer, Maritime Archaeology Sea Trust

Between August 1941 and May 1945, 78 convoys sailed from the UK, Iceland and North America to the Soviet Union as part of the vast Allied effort to supply the USSR during the Second World War. Over 1,400 merchant ships delivered almost four million tons of goods via this Arctic route. However, casualties were high, with at least 104 vessels lost to enemy action and extreme weather alongside 16 Allied warships. In turn, 34 German warships and submarines were sunk while hunting the convoys, as well as large numbers of aircraft.

Many of the wrecks are scattered across a vast and remote area of ocean, within the environmentally sensitive Arctic Circle, where pollution could cause serious harm and where spills may not be rapidly identified. These sites are hard to monitor using traditional maritime patrols, but new technology may provide a solution.

A new project funded by Lloyd's Register Foundation and carried out by the Maritime Archaeology Sea Trust (MAST) is working to address this issue. Researchers have scanned the archives to identify the locations of all military and merchant vessels lost in the area of the Arctic convoys during the First and Second World Wars. Each vessel is being assessed for pollution risk and compiled into a GIS database accessible to all project partners.

Using the data collected, MAST analysists will use a range of satellite-based remote sensing techniques to examine all the wreck sites identified for evidence of pollution over the last seven years. This approach has already been successfully applied in other regions to identify oil seeping from decaying wrecks and to spot catastrophic releases triggered by human interference such as salvage, fishing or military activity. The data will also be assessed for leaks which cannot be correlated with known wreck sites or subsea infrastructure, and which may indicate the location of previously unknown or missing wrecks. As Arctic waters once again face geopolitical tensions in the 21st century, it is hoped this technology will provide a means to manage the toxic legacy of 20th century conflicts.

6.2 Localisation and empowerment must be a central commitment

PPW management is just one example of a threat that is most keenly felt by communities with no part in creating it, nor access to resources sufficient to manage it. The obligation to put local knowledge and priorities at the heart of future management actions must be fully acknowledged. While large questions remain regarding how authentic localisation can be achieved, there is considerable experience of project co-design and co-production of knowledge available that can be drawn upon.[31] Strategic programmes such as the Lloyd's Register Foundation-funded network of Ocean Centres can help with stakeholder mapping and engagement, but focused effort is required to deliver meaningful empowerment.

FOCUS ON

USS *Mississinewa* in Ulith Lagoon, Federated States of Micronesia

Dr Polly Hill
Marine scientist

PPWs are predominantly risk assessed by the Global North nations responsible, through a lens that separates humans from nature and does not adequately allow for regional variability in priorities and vulnerabilities. A recent research project considered how risk assessment methodologies can better reflect and empower local priorities by examining the case of the USS *Mississinewa*.

The USS *Mississinewa* was deployed to refuel ships and aircraft at the Second World War Allied naval fleet anchorage in Ulithi Lagoon, now part of the Federated States of Micronesia. She was fully loaded with 19,000m3 of oil when she was struck by a Japanese Kaiten (a crewed suicide torpedo) on 20 November 1944.

In 2001, shortly after being located by visiting divers, the *Mississinewa* began to release oil, forcing the lagoon fishery to close to protect human health. The remaining oil was removed by the US Navy Supervisor of Salvage and Diving in 2003.

The study used analysis of interviews and official reports relating to the *Mississinewa* spill and subsequent oil removal to examine the efficacy of the risk assessment methodology used by the UK MoD to risk assess its own global inventory of around 5,700 PPWs. The following questions were considered:

1. Would the existing MoD risk assessment have identified the *Mississinewa* as a high-risk wreck?
2. How could the existing risk assessment better encapsulate vulnerabilities specific to Ulithians?
3. How can the risk assessment process be improved?

The MoD risk assessment did not capture: region-specific meteorological conditions; dynamite fishing which can cause PPWs to leak oil; remoteness making external resources slow to arrive; or the impact of fishery closures on traditional subsistence lifestyles and local biodiversity, including turtles and mangroves. The risk assessment would have classified the *Mississinewa* as a low-risk wreck due to a lack of infrastructure, shipping, tourism or commercial fishing in Ulithi Lagoon. Risk was determined in a way that deprioritised PPWs threatening traditional subsistence communities, while prioritising those threatening 'developed' communities with more resources to recover from oil pollution.

The following conclusions were made:

1. The existing risk assessment process did not sufficiently capture the impact of PPWs on traditional communities in remote locations.
2. Monetising impacts gives a short-term perspective of risk, ignoring the potential long-term impacts on communities and ecosystems.
3. PPW risk assessments should be place-specific and completed in dialogue with the people whose livelihoods or way of life will be impacted should a PPW release oil, capturing local risks, priorities, sensitivities and vulnerabilities.

The study therefore proposed that in locations where the local population is not equipped to effectively respond to and recover from an oil spill, a vulnerability assessment should be used to prioritise the survey of, and if appropriate, intervention on, PPWs. Further, a collaborative approach to PPW management was recommended to include local voices and recognise the unique vulnerabilities and priorities of those living alongside PPWs.

This contribution is an abridged and edited version of the full article that appeared in the Environmental Management journal.[32]

6.3 The development of international standards

From the outset, Project Tangaroa was guided by the proposition that international standards are an essential tool in development of a strategic approach to PPW management. A global community of experts exists with experience of creating and operating a range of PPW management systems, such as the standard operating procedure (SOP) employed by the SALMO wreck management team at the UK Ministry of Defence (see Appendix 1), which presents a simplified process for proactive PPW management, incorporating archival research and risk assessment followed by survey and remediation if deemed appropriate. Similar methods are used by a number of other countries.

It is now clear that these experts are ready to apply that knowledge to formulate a set of standards to underpin future work. There was clear consensus that the IMO is the most appropriate part of the UN system to engage with regarding such standards in the first instance. Opportunities may also exist to develop additional guidance and toolkits through engagement with the UN Environment Programme (UNEP) and UNESCO (UN Educational, Scientific and Cultural Organization).

Shortly before the launch of the Malta Manifesto on 13 June 2025, ICOMOS and IUCN published a Joint Statement on Potentially Polluting Wrecks (see Appendix 2), addressed to UNEP. ICOMOS has since reported that, in a letter dated 27 June, "UNEP welcomed the proposal to develop guidelines or a toolkit to evaluate and address the risks these wrecks pose to marine ecosystems, cultural heritage, and coastal communities. UNEP expressed readiness to collaborate and be guided by ICOMOS and IUCN leadership, underscoring its commitment to tackling marine pollution in alignment with the goals of the UN Decade of Ocean Science".

Immediately after the manifesto launch, PPWs were also noted as an important issue by the Secretariat of the 10th Meeting of State Parties to the 2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage: "Project Tangaroa demonstrates the need for cross-sectoral cooperation in protecting maritime heritage and aligns with broader climate and ocean protection goals. The Secretariat will continue supporting its development, especially in vulnerable regions such as Africa and Small Island Developing States".[33] This points to opportunities for broader discussions about PPWs with a range of UN bodies.

FOCUS ON

The National Oceanic and Atmospheric Administration (NOAA) – a 25-year legacy of PPW management

Doug Henderson
NOAA Regional Supervisor (retired)

NOAA's Office of Response and Restoration (OR&R) is the primary science advisor to the US Coast Guard (USCG) for oil spills, providing support for 150-200 annual incidents. NOAA's Office of National Marine Sanctuaries (ONMS) provides support in its network of marine protected areas.

They have led the US involvement with PPWs, starting in 2001 when a series of mystery spill events spurred a federal response. As research revealed the same oil type continued spilling for months, it was evident that it stemmed from a submerged source, not transient vessels. By February 2002, the source was chemically identified as the 1953 wreck of the cargo ship SS *Jacob Luckenbach*, 17 miles (27.3 km) off San Francisco, laden with 457,000 gallons of fuel and materials for the Korean War effort.

This was the catalyst for ONMS to start its inventory of shipwrecks, dumpsites and other hazards in and around national marine sanctuaries that could be potential pollution threats. In 2010, following several other PPW spills, the US Congress authorised NOAA $1 million to expand the shipwreck inventory to PPWs within the US EEZ and conduct a desktop risk assessment for the USCG to use in preparation for future oil spills from PPWs.

The 'Remediation of Underwater Legacy Environmental Threats' (RULET), completed in 2013, screened 20,000 charted wrecks in US waters. The study then identified 87 priority wrecks, and characterised the relative risk of catastrophic spill into the three categories: red (great), yellow (moderate) and green (low). This desktop study was based on research of the vessel's cargo, bunker fuel, sinking scenarios, potential oil spill trajectories (probable and worst-case scenarios) as well as environmental and socio-economic data for the region. The red or priority wrecks were added to NOAA's Environmental Response Management Application, regional USCG oil spill contingency plans and NOAA hydrographic surveys.

Since then, several of the priority vessels have been investigated and remediated. The remaining sites are routinely monitored by the NOAA Satellite and Information Service using high resolution visible satellite imagery and synthetic aperture radar. When a satellite report shows possible oiling near one of these wrecks, OR&R and ONMS works with the USCG and other partners to monitor, assess and respond as needed for clean-up and remediation.

FOCUS ON

Ensuring effective post-spill environmental impact assessment and monitoring

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Prompt and effective post-spill environmental monitoring helps to ascertain the risks and impacts on the human food chain, marine ecosystems and commercial marine resources. Monitoring also provides the data necessary to evaluate the effectiveness of response operations and any subsequent actions taken to mitigate impacts or promote recovery. Scientifically sound methods and processes must be incorporated into monitoring plans to ensure the results are fit for purpose and adhere to scientific standards. The PREMIAM (Pollution Response in Emergencies: Marine Impact Assessment and Monitoring) guidelines were introduced to provide a set of best practice principles for post-incident data collection and environmental impact assessment. They are now referred to in the UK National Contingency Plan.

These guidelines address the critical questions of why, where, when, what and how monitoring should be conducted. If a significant oil spill occurs, the initial response involves deploying containment and recovery equipment to minimise the spread of oil. Concurrently, the PREMIAM Monitoring Coordination Cell (PMCC) is activated. The PMCC then develops a monitoring plan, which may include collecting water, sediment and biota samples from various locations impacted by the spill, compared to baseline data for the area. Key aspects of the guidelines include:

1. Preparation and planning: a comprehensive monitoring plan outlining the scope, methodologies, and objectives. This would include identifying key environmental indicators, selecting appropriate sampling sites, and frequency of data collection.
2. Coordination of monitoring regime: the PMCC coordinates the activities and contributions from other agencies and organisations.
3. Data collection: during the incident, a range of environmental parameters would be monitored, including water quality, sediment composition, health of marine species.
4. Data analysis and interpretation: data would be analysed using robust statistical methods to assess the extent of the impact. Samples are analysed to assess the concentration of pollutants, impacts on marine life and potential risks to human health. The data collected is used to evaluate the effectiveness of the response operations and to identify any short, medium and long-term ecological impacts.
5. Reporting and communication: regular updates and reports would be produced for relevant authorities and stakeholders, including government agencies, environmental organisations and the public. Transparent communication would help build trust and ensure accountability.
6. Adaptive management: based on the evolving situation and ongoing monitoring results, strategies would be adjusted to address emerging issues and optimise the effectiveness of mitigation measures. Challenges and lessons learned would be collated between agencies to ensure improved process and review.

The guidelines are applicable to global incidents, with an update planned to enhance their relevance. This will include principles for monitoring in a wider set of global environments and to facilitate precautionary planning, enabling prompt and effective monitoring in the event of a spill.

6.4 Current oil spill response arrangements will not mitigate the PPW threat

The outcome of discussions at the workshops and meetings with the professional spill response community confirmed the working assumption that major PPW spills would not automatically be addressed through current response mechanisms. Not only is operational and logistical capacity already thinly distributed (and largely pre-committed), but most of the enabling funding mechanisms address contemporary spills from privately owned vessels and do not necessarily cover legacy matters such as PPWs. In certain regions threatened by PPWs, there is a major, persistent deficit in the availability of local workforces with the right skills and training for safe spill response. Furthermore, it is evident that while removal of oil from a PPW is currently an essential option, the subsequent safe transport and disposal of the waste oil has major logistical and financial challenges.

FOCUS ON

Workforce capacity in remote locations

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Oil pollution from PPWs poses particularly significant environmental risks in remote and ecologically sensitive regions such as the Arctic. A well-trained workforce, adequate infrastructure and strong community engagement are needed for effective spill response. However, challenges persist in skills, workforce availability and capacity. PPWs contain a variety of oil types, each presenting distinct operational and environmental challenges. Unfortunately, contingency plans are often outdated, not tailored to submerged wrecks, and lack detailed data on local resources at risk.

Figure 5: Spill response vessel and equipment mobilisation in Arctic Canada. This vessel and trailer setup demonstrates how spill response gear can be mobilised near shorelines when road access is not available. The vessel shown is equipped with a boom, ready for deployment in Arctic conditions.

Remote locations such as the Arctic face compounded difficulties. Specialised equipment and waste management facilities are scarce – mobilising resources can take over 48 hours and is costly. The expertise to maintain such equipment is often unavailable in small communities and harsh conditions can limit the effective use of this equipment. Establishing regional response hubs with pre-positioned equipment and trained personnel can help, but local capacity building remains essential.

In remote regions, local communities are the first to observe and report incidents and their knowledge of conditions and resources at risk is invaluable. Engaging them in all stages of preparedness and response planning is vital. A recent removal operation for grounded barges in Baker Lake (Nunavut, Canada) required the use of heavy machinery from a local mine and engaged local indigenous communities as workforce support. Local knowledge avoided the long mobilisation of external assets and strengthened collaboration between government agencies, industry and communities.

Recent Arctic spill incidents have suffered from poor reporting and documentation, delaying response efforts while making oil tracking difficult, underscoring the need for community-led preparedness.

A skilled and adaptable workforce is needed but training programmes often rely too heavily on theory, which may not resonate with hands-on learners. Practical sessions that leverage local knowledge and involve communities in training ensures relevance and effectiveness. Disconnects between external experts and local communities can undermine training outcomes. Training community members to lead initial response efforts ensures cultural appropriateness and sustainability. Seasonal activities such as fishing and hunting can limit responder availability, so educational programmes in schools and engagement with community elders can help build a resilient local workforce. Long-term funding is essential to support these initiatives.

FOCUS ON

Oil transport, reuse and disposal

Prof Craig Forrest
Director, Marine and Shipping Law Unit, University of Queensland

The removal, transport, reuse or disposal of oil from PPWs poses practical, legal and financial challenges especially in remote areas such as the Arctic and Pacific Islands.

Oil recovered from a PPW requires transport to appropriate facilities for reuse or disposal, such as by incineration. In the case of the USS *Mississinewa* the oil recovered was sold, offsetting some of the cost of recovery and transport. Incineration facilities in the Pacific are scarce, requiring long transport routes to Australian or New Zealand. Pacific nations already struggle with disposal of waste, and there can be significant regulatory burdens and financial costs on the exporting state. Existing arrangements are unlikely to cope with a large, unexpected increase in oil requiring transport and disposal.

A complex body of national, regional and international law applies to the transport and disposal of oil, especially where this involves transboundary transportation. These, plus broader international obligations in IMO conventions, such as the International Convention for the Prevention of Pollution from Ships (MARPOL) and UNCLOS, make for a complex matrix that many Pacific nations find challenging to implement given constrained resources.

Permitting requirements for hazardous waste disposal add another layer of complexity but will establish the administrative and technical conditions under which such waste must be managed. This could include ensuring the facility is designed, constructed, maintained and operated to protect public health and the environment, handling potential emergencies and spills, and cleaning up any contamination.

More storage capacity for the oil and other hazardous materials is needed. Temporary storage facilities must be designed to withstand the elements while waste awaits transport to final disposal facilities. These storage facilities must be large enough to avoid bottlenecks in oil removal operations. Additionally, waste volumes can exceed 10 times the volume of oil collected, necessitating substantial storage capacity to manage the increased volume effectively.

While practical and legal challenges exist for oil waste from many sources, the financial constraints may be more acute for waste oil from PPWs because there are no funding mechanisms like those under international legal conventions that impose liability on privately owned ships.

6.5 PPW workforce development and safety assurance

There are significant occupational safety risks associated with various aspects of PPW management. Many are common to a range of marine engineering and deepwater operations. Others are associated with the particular challenges of oil spill response in remote locations or where a trained local workforce is lacking – there is evidence of the harm caused by inadequate regard for safety. Volunteer effort and expertise from citizen science divers has an immense contribution to make to PPW survey and monitoring, and best practice is being codified. It is evident that, if ambitions for a globally impactful PPW management strategy are to be realised, there is a need for major workforce development across diverse sectors, and practices need to be codified and implemented.

FOCUS ON

The 2019 oil spill disaster off the coast of Brazil and its effects on the health of small-scale fishers

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Prof Louise Oliveira Ramos Machado
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From August 2019 to March 2020, oil slicks affected 1,009 locations across 11 Brazilian states. This included impacts to the most extensive coastline (over 1,800 miles/2,900km) recorded in tropical oceans.[34] [35] Approximately 5,380 tons of oil were removed from the beaches, impacting fishing and shellfish extraction territories and harming workplaces.[36] Due to the extent of the economic, social, and potential health damage, this was considered a public health emergency.[37]

It is estimated that the oil contamination resulted in socioeconomic impacts for about 150,000 artisanal fishers in the northeast of the country,[38] raising health concerns for these populations.[39] These workers spend 100 hours per week extracting and processing shellfish and fish on beaches, mangroves, and estuaries[40] – places where crude oil may permanently contaminate the ecosystem. Many volunteers, especially fishers, actively participated in the cleanup work but lacked training to handle oil collection or did not use adequate personal protective equipment. This resulted in an exposed population, potentially with health impacts, requiring a rapid response from the Public Health System (SUS).

The absence of reliable guidance on fish contamination led to recommendations for the generalised suspension of fish and shellfish consumption in the northeast. This reduction in the sale and consumption of fish harmed the economy throughout the fishing production chain, strongly impacting the income and lives of fishers and their families. Without being able to sell or consume fish there was an increase in hunger and malnutrition in addition to an expansion of the toxicological effects of the event because of the disaster.

Epidemiological studies in these populations identified high frequencies of oil spill exposure levels among fishers with the highest frequencies of high exposure found in oil removal activity (25.8%), compared to fishing activity (15.7%).[41] The fishers involved in clean-up activity were subjected to long working hours constantly in contact with material present in the environment (water, sand, mangrove mud) with high potential for oil contamination.[42] Among the neurological symptoms, the most frequent was 'severe headache or migraine' (38.4%). Fishers who helped remove oil/petroleum residues were twice as likely to have neurological symptoms as those who did not help.[43] The studies also highlight that the prevalence of respiratory symptoms, such as stuffy nose (28.4%) and burning in the nose, throat, or lungs (22.7%), is substantially higher in individuals exposed to high levels of oil during fishing and removal activities. Effects on mental health were also identified. The populations most affected by the disaster – small-scale fishers – are predominantly of African descent.

Given the above, it is necessary to implement more robust and structured public policies in fishing communities, aiming to ensure social, economic, and health equity, reducing exposure and vulnerability to possible future events. Furthermore, it is of extreme importance to strengthen the environmental policies of conservation units and workers' organisations. This will ensure the maintenance and sustainability of traditional peoples, and promote sustainable projects and income generation.

FOCUS ON

A framework for citizen-led monitoring of PPWs

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Dr Andrew Viduka
Founder and Director, GIRT Scientific Divers Pty Ltd

The Nautical Archaeology Society's (NAS) PPW initiative in the UK and the GIRT (Gathering Information via Recreational and Technical) Scientific Divers project from Australia are demonstrating how community-led monitoring can help address the PPW hazard. These programmes set the stage for transforming passive observations into actionable insights – turning informed citizens into active stewards of ocean health.

The NAS scheme builds on over 40 years of community archaeology and citizen science. By engaging with dive clubs, fishing collectives and harbour authorities, awareness of PPWs is being raised, and these group's capacity for safe and effective data collection can be assessed. Collaboration with the UK MoD and the Marine and Coastguard Agency ensures the collected data aligns with their operational needs. These insights will help shape fit-for-purpose reporting into national PPW management programmes. By increasing visibility of PPWs as an environmental and safety hazard, the NAS PPW scheme empowers both professionals and recreational users to take preventive action. This initiative will be internationalised through NAS's global training network.

GIRT Scientific Divers, endorsed by the UN Intergovernmental Oceanographic Commission as an Ocean Decade Action, is an established conservation focused, no-impact, underwater cultural heritage (UCH) site monitoring citizen-science project. Members use the GIRT methodology to document physical and natural features of UCH – condition reports are shared with the public. GIRT collaborates internationally to teach the public, dive charter businesses, marine parks, NGOs, museums, regional universities and government heritage agencies to better monitor UCH.

GIRT is collaborating with researchers from the National Museum of the Philippines and the University of the Philippines Diliman, and a local dive shop in Subic Bay, to establish baseline data and monitor the PPW *El Capitan*. Further analysis of the site data and effectiveness of this citizen science approach will be undertaken post fieldwork.

The citizen science work on PPWs by NAS and GIRT is funded by Lloyd's Register Foundation, as part of its Small Grants programme.

FOCUS ON

A safety framework for citizen science divers on PPWs

Prof Alessandro Marroni, Laura Marroni, Massimo Pieri, Dr Riccardo Pelliccia and Costantino Balestra
DAN Europe Foundation

Citizen science promotes inclusivity, sustainability, and public involvement in research. Its core principle is that non-professionals, when following scientifically validated protocols, can meaningfully contribute to data collection and scientific progress. This approach leverages the statistical law of large numbers: with many independent observations, aggregated data becomes highly reliable.[44]

Citizen science has mainly flourished in environmental and cultural heritage fields, where volunteers collect data using standardised protocols.[45] [46] [47] Yet, a crucial component often overlooked in citizen science diving and scientific diving is diver safety – especially in extreme environments – typically treated as a separate, medical concern. This gap is now being addressed by the work of Working Group 1 of ISO Technical Committee 228, which has drafted new international standards specifically for citizen science divers. These include diver safety and human physiological and behavioural research as integral components of scientific activity.

DAN Europe has taken a pioneering role in this space by developing a comprehensive citizen science training and monitoring programme. It equips divers with tools to collect structured dive and physiological data before, during and after dives. A user-friendly web platform enables contributors to log personal and dive data, feeding into a dynamic, freely accessible international database – the outcome of years of applied research and fieldwork.[48] So far, over 135,000 dives and over 620 decompression sickness cases have been logged, enabling the identification of key risk factors – individual, environmental and behavioural. This has led to the development of probabilistic models to estimate risk and personalise decompression strategies.[49]

By integrating these tools and data into citizen science projects on PPWs, DAN Europe contributes a robust safety framework grounded in evidence, prevention, and continuous learning. This ensures that non-professional divers engaged in meaningful scientific work can do so with the same level of risk awareness and physiological monitoring as professionals – a key step toward more ethical, inclusive and safe underwater research.

6.6 Scaling up PPW management demands new approaches

Strong industry participation at the workshops provided ample evidence that proven, robust technologies and techniques exist to manage PPWs. The challenge remains, however – can existing techniques be applied at scale at a manageable cost? If not, what innovation is required to enable massively scaled-up activity? The following contributions explore different aspects of this challenge.

FOCUS ON

Mobilising for a wreck assessment survey

Simon Burnay
Chief Executive Officer, Waves Group

Following a desktop risk assessment, if it is determined that a particular wreck warrants further assessment, then the standard approach is to conduct a detailed in-water survey of the wreck to assess its actual condition, identify any ongoing leakage of oil and to confirm the presence of oil remaining in its tanks. Such surveys are complex operations, utilising deep sea capable vessels, remotely operated vehicles (ROVs), high-resolution survey equipment and potentially, the use of advanced non-intrusive technology to 'sample' the tanks and determine the potential volume of oil in the wreck. These operations require careful planning and management of costs.

One such example is the wreck of the HMS *Cassandra*, located in the Baltic Sea, in Estonian waters. A detailed survey and risk assessment of this wreck was completed in 2025 for the UK MoD (SALMO), led by Waves Group. The planning of this survey drew heavily on the team's collective experience of deep-water wreck surveys to enable the quantification of the risk posed by the wreck, including:

- Desktop review of the wreck, historical records, previous survey data, publicly available imagery (e.g. dive videos), drawings of the vessel and local environmental conditions.
- Vessel selection, appropriate to the location and conditions, to provide a safe working platform for the survey equipment and personnel, with minimum weather downtime. Vessel availability can be a challenge, as multiple sectors are often competing for the same assets.
- Survey equipment selection to ensure that the wreck can be accurately mapped to enable a detailed assessment of its condition and residual oil. This included ROVs, multi-beam sonar and photogrammetry. All equipment was selected to meet the output criteria, with maximum operability in the expected environmental conditions.
- Obtaining permits and approvals for the relevant jurisdictions and maritime authorities, including archaeological requirements (preservation of UCH).
- Mobilisation procedures to ensure that all survey equipment is operational, properly interfaced and tested. This is critical to ensure the veracity of the data obtained.
- Logistics requirements that satisfy all customs and import requirements.
- Team composition to ensure successful data acquisition and assessment, including ROV pilots, hydrographers, marine archaeologists, data processors, naval architects and salvage specialists.
- Geo-political situations to ensure that the survey can proceed safely and effectively.
- Survey procedure to plan for how the survey and assessment will be conducted to give maximum quality of data acquired and enable the full risk assessment of pollution risks.
- Data processing, interrogation and dissemination requirements.
- Project management and cost management to ensure that the project budget is met.

Figure 6: mobilising for the survey of HMS *Cassandra*.

Significant cost savings (easily running to millions of US dollars) can be made by conducting operations on multiple wrecks in a campaign. This requires extensive planning and sequencing due to the longer mobilisation and operational times, including considerations such as crewing requirements, replenishment needs, data storage and transfer (each wreck creates large volumes of data) and prior arrangement of permits. Indeed, a plan to conduct multiple surveys of PPWs in 2025 in conjunction with that of the *Cassandra* was prevented by a slow permitting process – a clear demonstration of the challenges faced in trying to scale up the response to the PPW problem.

Even with the utmost urgency (which is becoming ever more prevalent for PPWs), professional mobilisations for wreck assessments and interventions require proper time for planning and preparation, to give the best certainty in the outcome.

FOCUS ON

Oil removal – can current practice be scaled?

Paul van't Hof
Operations Manager, SMIT Salvage

Matthew Bierwagen
Director, Resolve Marine

Techniques for removing oil from wrecks, such as hot tapping, are proven and commonly employed in the commercial marine salvage sector. They have been successfully deployed on many high-profile marine salvage operations, including the *Costa Concordia* (Italy) and the *Erika* (France), and on PPWs, such as the HMS *Royal Oak* (UK) and the USS *Mississinewa* (Micronesia).

Oil removal operations are complex and can involve locating and identifying the wreck, surveying and inspecting it to identify suitable pumping locations, mobilisation of equipment and personnel, preparation of the hull, installation of the hot tap valves and systems, heating of the oil and pumping to the surface for storage onboard the receiving vessel. Following removal, the oil must be transported to an appropriate shore facility for re-use or recycling. Such operations often requiring extensive dive operations, including saturation diving if the wreck is in deep water. The use of high-capability work class remotely operated vehicles (WROV) can help to reduce the need for dive operations. However, whatever the primary method of conducting the operation, the scale of the vessels and equipment required to safely conduct professional operations in offshore and exposed waters is expensive to deploy and can involve extended durations.

Figure 7: The successful removal of oil from the wreck of the *Coimbra* (a tanker sunk off New York, USA during World War II containing 1,500 tonnes of oil), conducted by Resolve Marine, required a team of 83 people and 193 dive sorties to complete the operation in approximately three months offshore.

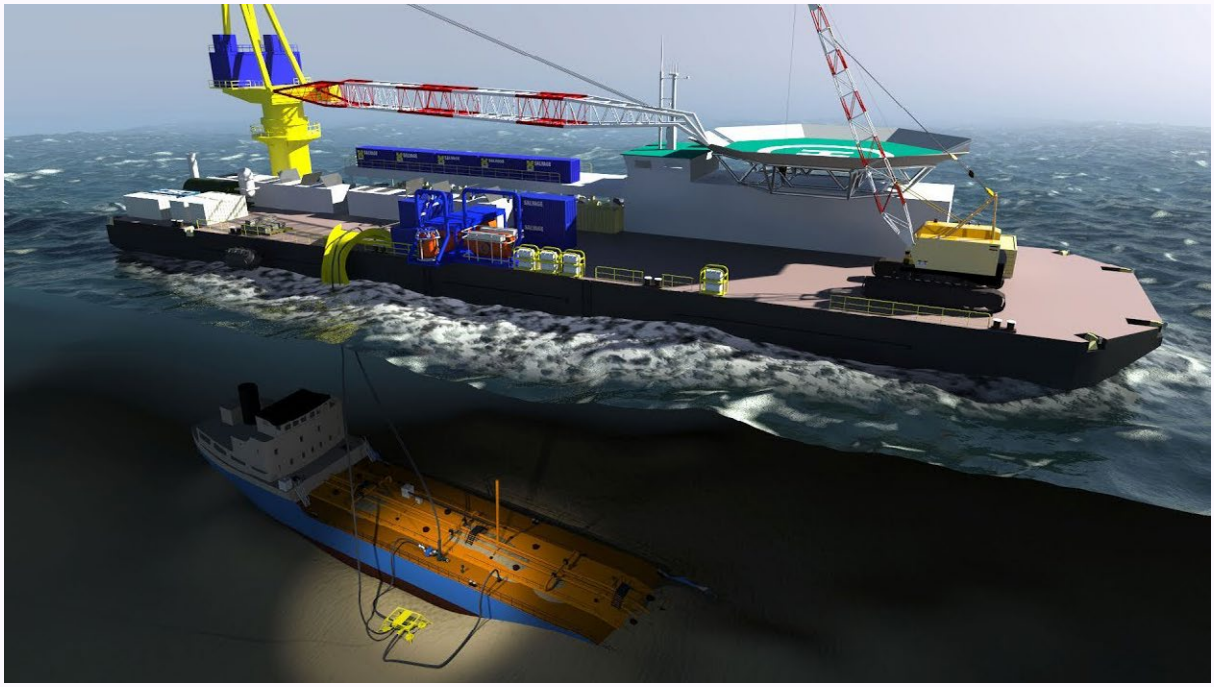

Figure 8: The tanker *Kyung Shin* sank in 1988 in 100m deep water. SMIT Salvage successfully removed over 500 tonnes of heavy fuel oil from the vessel using hot tap techniques from a spread that included an offshore crane barge, support tug, saturation diving system and oil heating systems, mobilised from Europe, the Middle East and Singapore.

The successful removal of oil from the wreck of the *Coimbra* (a tanker sunk off New York, USA during World War II containing 1,500 tonnes of oil), conducted by Resolve Marine, required a team of 83 people and 193 dive sorties to complete the operation in approximately three months offshore. The tanker *Kyung Shin* sank in 1988 in 100m deep water. SMIT Salvage successfully removed over 500 tonnes of heavy fuel oil from the vessel using hot tap techniques from a spread that included an offshore crane barge, support tug, saturation diving system and oil heating systems, mobilised from Europe, the Middle East and Singapore.

PPWs have particular challenges due to their age and the degrading condition of the hull structures and piping systems. Hot tap systems require physical connections to be made to the hull, which must therefore have sufficient structural strength to avoid the failure of the hull plating and the accidental release of the oil contained within. As corrosion of the hulls accelerates, then this problem will inevitably be seen on more wrecks. Further, it can be impossible to completely remove all oils from a PPW. Small quantities can become trapped in the structures which cannot be pumped, which can be exacerbated by internal migration of the oil (due to breakdown of tank walls and piping). It is generally not practical or economically viable to remove every drop and these 'unpumpables' should be planned for as part of the wreck management plan.

With potentially thousands of PPWs requiring intervention, the scale of the problem is another challenge. There is a relatively small number of hot tapping systems available globally that are suitable for all PPWs and all oil characteristics. Additionally, these must be supported by experienced personnel and deployed with suitable vessels and equipment to complete these operations. Given the challenges of deploying hot taps on degrading hulls of PPWs, then we must also develop other methods of removing oil that can be scaled and deployed globally, but flexibly, to account for the number and range of wrecks requiring intervention.

FOCUS ON

Technology, innovation and democratisation

Prof Fraser Sturt
Deputy Director, Southampton Marine and Maritime Institute

Addressing the scale of the PPW challenge requires drawing together a variety of different data types. Currently, most methods for doing so are expensive in terms of both money and carbon. There are, however, clear indicators of change on the near horizon which could transform our understanding of the threat posed and democratise access to key capabilities.

At present, location and identification of wrecks in water depths over 100m often requires a large ocean-going vessel and large WROVs. These can create highly detailed 3D models of shipwrecks from bathymetric and photogrammetric systems. The running costs, however, are high, meaning that large area survey, or even prospection, is unlikely to occur. Most often PPWs are investigated in this manner once a problem has presented itself, or as part of established monitoring programmes.

Autonomous underwater vehicles (AUVs) now offer a different suite of options. Recent work has seen AUVs carry out 'over the horizon' operations. This could mean launching an AUV from shore and carrying out a survey for several weeks. In the recent AT-SEA project led by the National Oceanography Centre with the University of Southampton, an AUV was deployed with a camera system to map and record offshore oil and gas infrastructure. The resulting data was of exceptional quality, pointing to a lower cost, lower carbon means of documenting and mapping the oceans. As this technology has progressed smaller and cheaper AUVs have been developed, opening this technology up for a wider range of applications.

However, AT-SEA does not provide all the information that would be needed to monitor or risk assess a wreck. The addition of new sensors or ways of capturing additional information via AUVs, ROVs or other platforms, offer additional hope. The technology nearest delivery is water sampling systems mounted on AUVs to gather a sample and return it for analysis. This could be used to establish if a wreck is contributing to a pollution incident. Further developments of lab-on-chip sensors will in time allow for different chemical signals to be processed directly on the AUV. This combined with their ability to be at sea for longer periods will allow for extended monitoring scenarios.

In deeper waters these technologies will remain comparatively expensive, requiring larger AUVs and greater power. However, the miniaturisation of AUVs and ROVs is moving at pace, with increasingly reliable systems available, with sidescan sonar or camera systems on board. This opens up the potential for more data to be gathered more cheaply at the frequencies required to enable both prospection and monitoring.

6.7 Climate impacts: new stresses on a stressed system

Across the ocean stewardship community there is a clear imperative to understand the impact of climate change and to develop strategies that address opportunities for mitigation but increasingly acknowledge the need for adaptation. Recognition of climate impacts demands a new urgency in terms of putting in place a PPW management strategy.

FOCUS ON

PPWs and climate change – a call to action

Dr Jeneva Wright
Innovation Development Lead, Henry M. Jackson Foundation

Climate change presents urgent, ongoing and intensifying impacts to global cultural heritage, and management pathways are still developing.[50 51 52] UCH sites are particularly threatened, as they are often 'out of sight, out of mind', and less research exists on climate impacts.[53 54 55] For UCH, climate adaptations are further slowed by limited understanding of localised environmental preservation factors. This results in delays or incomplete information needed to develop vulnerability assessments, adaptation menus and management strategies. These data gaps are critically important for PPWs where climate change hazards go far beyond damage to UCH.

Recent research at the battleship USS *Arizona*, a casualty of the 7 December 1941 attack on Pearl Harbor, Hawaii, offers a potential pathway for the integration of underwater archaeology, climate change response and PPW management. Due to its status as one of the most iconic shipwreck sites in the world, this United States national monument, war grave, and leaking container of an estimated half-million gallons of Bunker C fuel oil, was the subject of decades of research to model its stability.[56 57] Through the use of extant data on hull stability and environmental parameters, this site served as a case study for adoption of an emerging cultural heritage climate adaptation framework.

The result was the production of the first vulnerability assessment and adaptation menu for a UCH site with direct application to its multiple heritage values.[58] It confirmed that climate change will pose a threat to the preservation and stability of USS *Arizona*. Rising sea temperatures and acidification were the primary factors of concern. Identifying vulnerability was a powerful initial step, but also directly informed several potential management actions that were developed, evaluated and collated into an adaptation menu with prioritised, low-risk and high-utility actions recommended for management.

The research at USS *Arizona* offers pathways to incorporate climate change response into the management of PPWs with known locations and ideally, baseline conditions. Data requirements include current conditions, materials and environmental factors of concern to produce both a vulnerability assessment and a robust adaptation menu. This does not generally require immense data collection, but rather a reasonable familiarity with the site(s) in question and their environment. The quantity and diversity of data produced for USS *Arizona* are not necessary to take the next steps in climate change response, but the quality of data on local conditions, site characteristics and management paradigms directly correlates with more effective vulnerability assessment and adaptation development.

Climate management for UCH is in its infancy. The focus is so deeply centred on documentation that the necessary next steps of adaptation to rapidly changing environmental conditions are falling behind. Data on PPWs can be leveraged to produce management actions that acknowledge and integrate climate change response. With the will to integrate climate response, we are well positioned to tackle the critical challenges of PPWs within the crisis of climate change.

FOCUS ON

UNESCO white paper on underwater cultural heritage and climate change impacts

Prof Colin Breen
Associate Head of School of Geography and Environmental Sciences, Ulster University

In 2025, at the tenth session of the Meeting of the States Parties of the 2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage, a White Paper on *Underwater cultural heritage, climate change: adaptation and mitigation* was presented.[59] The paper was prepared in support of the work of the Secretariat of the Convention and is framed as part of UNESCO's initiatives around culture and climate action.

The linkages between cultural heritage and climate change have been systematically explored, yet UCH remains insufficiently translated in public policies. The paper highlights a need to strengthen the rationale for governance and investment – including access to climate finance. The paper aims to identify appropriate culturally-informed adaptation measures for the protection of UCH and the production of science-led mitigation strategies. The document also seeks to identify capacity-development opportunities and addresses the need to include indigenous, as well as community voices on a more equitable level.

The paper emphasises that UCH must be viewed through an inclusive nature/culture lens. Recommendations to UNESCO that may be particularly relevant to PPW management include:

- Establishment of a UNESCO commission or working group on climate change adaptation and UCH.
- Undertaking scientifically-informed, area-based threat and vulnerability baseline assessments of the impacts of climate change on UCH.
- Full integration of UCH and maritime cultural heritage (MCH) in national, regional and international policy with regards to marine spatial planning.
- Production of adaptive guidelines on how UCH can be integrated into disaster risk reduction, disaster risk management and post-disaster needs assessment.
- Development of support mechanisms for the full integration of UCH and MCH into area-based marine protection frameworks including the Marine Protected Area (MPA) network.
- Development of resources including toolkits and protocols that support professional networks on matters such as climate vulnerability and mitigation for UCH and area-based protection strategies, including MPAs.

6.8 Illicit interference increases the risk of a major spill

Hard evidence is now available that illegal salvage and interference with PPWs is materially increasing the risk of a major spill. Satellite surveillance has been instrumental in confirming this and will be important to future monitoring efforts.

FOCUS ON

Combating illegal salvage

Jessica Berry and Giles Richardson
Maritime Archaeology Sea Trust

The Maritime Observatory is a partnership between not-for profit group OceanMind (OM) and the Maritime Archaeology Sea Trust (MAST). The Observatory uses a combination of satellite technology, intelligence and AI to identify bad actors at sea to prevent or deter the looting of shipwrecks. AI enables real-time identification of incidents – these are investigated, and MAST's and OM's combined work is provided to the relevant authorities.

UCH is being weaponised by malign and non-state actors. HMS *Prince of Wales*, sunk by Japanese aircraft in 1941 in the south China Sea had remained intact until about 10 years ago. In April 2023 a TikTok video was posted by a scrapyard operator in southern Malaysia; it appeared to show one of the ship's anti-aircraft guns being unloaded. The Observatory identified the barge as the Chinese-owned *Chuan Hong 68* which had previously been tracked interfering with sites in Indonesia six years ago. Malaysian police raided the scrapyard and seized most of the wreckage, including piles of ordnance.

The Observatory built a forensic case that conclusively linked the barge to the *Prince of Wales* site. Reconstructing the AIS track, the vessel clearly made a number of journeys from the yard towards the *Prince of Wales*. But on each occasion the AIS signal went dark about 100 miles (161km) from the wreck site – the salvors were undoubtedly aware that the site was being monitored. The Observatory used a combination of satellites – electro-optical and synthetic-aperture radar – to provide the Malaysian authorities with sufficient intelligence to prosecute. Both proved they had been activity there during the *Chuan Hong* dark period. A 6.2 mile (10km) oil slick was also detected while it was over the site (most likely from the *Prince of Wales*'s fuel tanks). An environmental disaster was only averted through pure chance thanks to favourable wind and tide.

Further investigations revealed that *Chuan Hong* had been conducting a widespread campaign. The targets were mainly UK and Japanese warships of the Second World War including a Japanese heavy cruiser and a Japanese minelayer. *Chuan Hong* actually had legitimate salvage contracts for at least two vessels. But the AIS signal pattern showed it was also operating over – and damaging – a nearby historic wreck.

6.9 Finance: a high-ambition pathway must be created

Improving access to finance and other resources was undoubtedly a focus of concern during the Project Tangaroa workshop series. Delivery of a comprehensive PPW management strategy will entail financial support for a wide range of activities; some of these can be funded by research funding bodies, government agencies or foundations. But that funding is neither adequate nor predictable. Moreover, at the heart of this challenge is the need to rapidly improve protection for some of our most vulnerable communities and environments. This cannot be achieved on a piecemeal basis and demands a high level of ambition in development of solutions.

FOCUS ON

The case for a PPW finance task force

Mark Spalding
President, The Ocean Foundation

Safe management of PPWs is one of the most significant, unfunded environmental burdens in our global ocean. Yet we continue to approach this challenge through fragmented, ad-hoc mechanisms that are fundamentally inadequate for the task at hand. Purposeful innovation is required to find solutions, but this will be futile without deep commitment to international cooperation.

Multilateral funders, like development banks and UN agencies, are essential partners but the level of need far outstrips their current capacity and mandate. The bureaucratic processes inherent in multilateral institutions, though necessary for accountability, do not match the urgency of many PPW situations.

A diversified approach is needed that blends the legitimacy and scale of multilateral finance with the agility of commercial mechanisms, the innovation of entrepreneurial models and the rapid deployment capability of specialised funds. No single mechanism can address the full range of PPW challenges across various regions, wreck types, pollution risks and timeframes.

This challenge requires specialised expertise and focused attention that go beyond traditional environmental or maritime policy frameworks. A PPW finance task force (FTF) would unite the unique combination of skills, relationships and authorities necessary to create innovative funding solutions at the necessary scale and speed:

- Specialised financial expertise: a deep understanding of complex financial instruments is needed, such as environmental bonds, insurance products, public-private partnerships, and innovative funding mechanisms that cover multiple jurisdictions and stakeholder groups.
- Cross-sector relationship building: creating trusted relationships with a diverse range of stakeholders is critical, including multilateral development banks, commercial insurers, shipping industry leaders, sovereign wealth funds, impact investors and government treasury departments.
- Rapid response capability: an FTF could pre-negotiate frameworks, establish rapid deployment procedures, and ensure ready access to emergency funding sources that are impossible to arrange on an ad-hoc basis.
- Innovation and pilot testing: many mechanisms will need experimentation, refinement and adaptation based on real-world experience. A dedicated FTF could oversee multiple pilot programmes simultaneously and quickly scale successful approaches.
- Accountability and transparency: given the moral dimensions of PPW remediation and the involvement of public and multilateral funds, a specialised FTF can assure transparency and public accountability.

We do not need to reinvent the wheel. Successful global funding mechanisms, such as the Global Fund to Fight AIDS, Tuberculosis and Malaria and the Climate Investment Funds, demonstrate how to blend public and private funding, create market mechanisms and maintain donor commitment over the long term. These models can be adapted to address PPW challenges.

The FTF requires a leadership group with sufficient authority to negotiate the large-scale commitments across sectors needed to mobilise billions of dollars in funding. Senior leaders from multiple sectors will therefore be needed to work with the task force. These should include: former senior officials of multilateral development banks; senior treasury officials from major maritime nations; insurance industry executives from the marine and environmental sectors; experienced environmental finance specialists; representatives from major shipping companies and maritime industry associations; and representatives from impacted communities.

Failure to establish this FTF – with the right senior leadership to act with urgency and resolve – would be an abdication of responsibility. Inaction will deepen injustice caused by catastrophic environmental damage and economic devastation. Many coastal nations facing the most pressing PPW threats were not in existence when the warring nations sank these vessels, but they are likely to suffer significant impacts to their lives and livelihoods, which depend on clean, healthy coasts and ocean. There is a clear moral imperative, if not a duty, for nations to cooperate in remediation efforts and prevention of catastrophic harm.

6.10 Knowledge of, and access to, information sources on PPWs is highly variable

There is a massive deficit of available information on the location and condition of the vast majority of PPWs. Management efforts are also hampered by a general lack of environmental baseline data for PPW locations. Development of a strategic approach to addressing these deficits is a key priority. There are multiple archive collections and sources of relevant scientific data that could contribute to meeting this challenge. Portals and indices – as illustrated in the examples below – have been produced with the intention of making users more aware of such sources of data but further signposting and guidance is needed.

FOCUS ON

Data and Blue Pacific PPWs

Dr Matt Carter
Research Director, Major Projects Foundation

The Blue Pacific contains over 3,800 actively and potentially polluting wrecks, holding an estimated 500,000 to 4 million tons of pollutants, primarily oil. Notably, 86% of these wrecks are of Japanese origin and 10% American, with almost none belonging to Pacific Island countries or territories, highlighting a colonial and wartime legacy that continues to threaten local ecosystems.

Since 2018, the Major Projects Foundation (MPF) has conducted extensive research across the Pacific. At the Bikini Atoll World Heritage Site, MPF surveyed 12 shipwrecks, creating detailed 3D models from over 580,000 photos. In the Federated States of Micronesia, under a 1.4 million USD Australian Government-funded project with SPREP[c], it mapped 43 wrecks with nearly 800,000 images. Using sophisticated mapping techniques to produce detailed 3D models, these efforts identified significant oil pollution risks from intact fuel compartments in many vessels.

Data dissemination faced substantial hurdles including complex stakeholder permissions, high permit fees and multi-layered approval processes. Technical challenges include managing 75TB of data, disputed intellectual property rights, ownership of wreck coordinates, conserving natural and cultural heritage, and data sovereignty. Different agencies require specific permissions with varying expectations and data usage protocols.

MPF's success stems from relationship-building and respecting data sovereignty. Its approach establishes trust with local communities, formalises data-sharing agreements before collection begins and maintains flexibility across diverse Pacific contexts. By acknowledging both technical complexities and cultural sensitivities, MPF has developed protocols that respect indigenous data rights while advancing environmental protection.

Progress continues through agreements, though intellectual property issues remain challenging. MPF's experience demonstrates that effective environmental protection requires technical expertise and understanding stakeholder concerns. Future projects will benefit from early establishment of data governance frameworks that accommodate both scientific needs and cultural values. The SPREP Pacific Environment Data Portal offers a promising platform for regional data sharing that respects sovereignty while enabling coordinated environmental management efforts.

c SPREP (the Secretariat of the Pacific Regional Environment Programme) is an organisation established by the governments of the Pacific to protect and manage the region's environment and natural resources.

FOCUS ON

Archives and data

Louise Sanger
Head of Research, Interpretation and Engagement, Lloyd's Register Foundation Heritage Centre

Desktop assessments use primary and secondary source material to build an understanding of different wrecks. Location, damage, changes and refits to vessels can make identification difficult without detailed archival research. Although there is a breadth of information available online, digitised archival material as a primary source is invaluable, as are archive catalogues to locate relevant physical material. The more accessible these resources, the better informed any subsequent action.

Lloyd's Register Foundation Heritage Centre collections come from centuries of operation by the classification society, Lloyd's Register. Classification is the laying down of standards, the approval of construction and subsequent maintenance of ships. Through this process, a rich record of the condition of vessels is created. Freely available digitised resources include over 1.15 million digitised ship plans and survey reports dating from 1834 to 1960), including the Wreck Report series (1892-1940) of classed vessels lost by shipwreck, war or demolition. These records contain casualty/incident details, correspondence with the shipowner and between offices, and relevant newspaper articles. Also available are *Lloyd's Register of Ships* (1764-1998), *Rules and Regulations for the Classification of Ships* (1834 onward) and *Casualty Returns* (1891-2000).

Surviving classification records can provide details on vessel construction, modifications, cargo, propulsion, bunkering, and ammunition stores. Not all ships were classed by Lloyd's Register, and not all classification society records have survived – those that have are often incomplete or inaccessible. Many vessels were never merchant vessels, so the archival search area broadens further to include naval and other records.

Enhanced online access to digitised archive material is becoming increasingly important for PPW management. Timely access to shared knowledge is vital, and projects that explore ways to link up and signpost cultural heritage collections with other types of data underline the value of collaboration. Examples include Unpath'd Waters (a three-year research project that developed digital solutions for easier access to UK maritime records) and OceanInfoHub (designed to address the challenges and complexities of finding and sharing ocean data online). A PPW data access and archive strategy is needed to support organisations to make the case for maximum possible open access to this invaluable material.

6.11 The legacy of war poses complex safety and management challenges

Project Tangaroa stakeholders initially questioned why the workshop programme did not include detailed consideration of munitions – both within PPWs and in dumps. The need to address munitions was fully acknowledged. However, it was agreed that its focus should be the threat from oil as cargo and fuel in legacy wrecks. Oil involves distinct categories of impact (including wide area impacts) that need to be recognised as a priority to address in emergency response plans and long-term management, along with specific regulatory and legal regimes that states and international organisations may deem necessary or appropriate. In addition, existing projects such as REMARCO are focused on munitions and close collaboration with that programme, among others, has been initiated.

There was also much discussion on the issue of human remains associated with PPWs and it is evident that for flag states such as Japan, this issue is highly influential in approaches to PPW management. It is also an issue identified as important in the UNESCO 2001 Convention on the Protection of Underwater Cultural Heritage and the International Agreement on *Titanic*.[60] No consensus has been reached to date on how to address this sensitive issue in a standard, regulation or policy framework, except to say that the remains need to be treated with respect.

FOCUS ON

The REMARCO project

Dr Matthias Brenner
Marine Biologist, Alfred Wegner Institute Helmholtz Centre for Polar and Marine Research

REMARCO stands for Remediation, Management, Monitoring and Cooperation addressing North Sea unexploded ordnance and is a European project funded by Interreg North Sea. It is based on a consortium of 10 partners from academia, state agencies and private companies from Belgium, Germany and the Netherlands. More than a dozen experts were invited to the project's advisory board, helping to connect the project to the most important stakeholders in national and EU politics and administration.

REMARCO started in mid-2023 as a follow up of the North Sea Wrecks project, but with a broader scientific scope from war wrecks containing munition towards the assessment, monitoring and potential remediation of munition hotspots in the North Sea. Sites where REMARCO detonated munitions in-situ at beaches, tidal banks and underwater (see figure 9) were surveyed and assessed for their chemical emissions. New monitoring techniques using an underwater crawler to semi-autonomously take water, sediment and biota samples were tested at distinct areas of the wreck of SMS *Ariadne* (see figure 10).

Figure 9: Blast in place operation near Bornholm (U. Marx 2023).

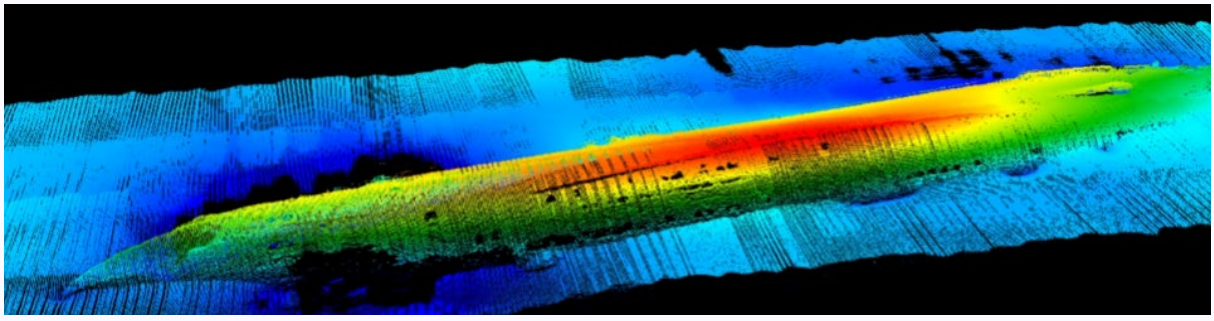

Figure 10: Multibeam image of SMS *Ariadne* (DLR 2022).

Basic research about toxicity of dissolved explosives to marine organisms, including how this is impacted by rising temperatures caused by climate change, is also being conducted. All data is fed into a software-based risk assessment tool, helping to categorise munition hotspots according to their environmental risk. Results are presented to organisations such as OSPAR – responsible for marine environmental monitoring – and UNESCO, because of the heritage status of investigated wrecks. National war grave organisations are consulted if remediation activities at the wreck site are conducted.

FOCUS ON

The Log Book Project

Nick Devaux
Chief Executive Officer, The Log Book Project

Research to understand the pollution threat from war wrecks can be intertwined with investigations into the heritage significance of these vessels and the human stories attached to them. One such instance is The Log Book Project (TLBP), in which over 270 veterans and civilian witnesses from both sides of the Second World War have signed and shared their stories.

Figure 11: Cyril Devaux.

The project uses the logbook of Cyril Devaux (figure 11), a St. Lucia-born born pilot who served in the Royal Air Force. In 2016, 70 years after his last flight entry, an unrelated story of a Japanese fighter pilot inspired an initiative to collect autographs on the unused pages in Devaux's logbook.

Several signatures from the Caribbean theatre of the Second World War were obtained in the logbook. One of these was from Mike Mair, whose father John served aboard the USS *Mississinewa* – a tanker sunk at Ulithi in the western Pacific in October 1944. In 2003, 1.8 million gallons of oil were removed from its leaking wreck (see page 24). However, the *Mississinewa* might just as easily have been a Caribbean PPW. In June 1944, it took on a full load of fuel in Aruba, and had to evade a German U-boat on leaving the harbour, before making its way to the Pacific via the Panama Canal. Had *Mississinewa* been sunk in the Caribbean, it would have been with over twice as much oil onboard as was removed at Ulithi almost 60 years later.

The Caribbean's strategic importance for the transport of oil, combined with limited Allied defences, meant that a large number of tankers were lost there, many fully laden with oil. Spurred by the *Mississinewa* connection, a research by TLBP revealed 33 fuelled tankers sunk in the Caribbean with a combined cargo of over 90 million gallons of oil and refined petroleum. To date, no comprehensive, publicly-accessible survey has been conducted to evaluate the risk posed by these shipwrecks, which are among over 300 ships sunk in the Caribbean during the Second World War.

TLBP was conceived to as a tribute to those who served in the Second World War and to further understanding of the trauma it caused. But the initiative also led to the discovery of Caribbean PPWs, thus motivating the project to research and raise awareness of the issue. TLBP has now established itself as a source for Caribbean PPW data, and has advised the Organisation of Eastern Caribbean States Commission to examine the matter at the regional level.

FOCUS ON

PPWs from a Japanese perspective

Chihiro Nishikawa
Research Fellow, Kobe University

Japan has established laws and policies to protect its cultural heritage and to show respect for human remains on land. These frameworks are now gradually evolving to include UCH. For instance, the Takashima site in Nagasaki Prefecture, where Kublai Khan's fleet was destroyed during the Mongol invasion of 1281, was designated in March 2012 as the country's first UCH site under the 1950 Act on Protection of Cultural Properties.

Japan is one of a number of countries that has stated that sunken state vessels, including warships and government service vessels, remain the property of the flag state at the time of sinking unless that state formally relinquishes ownership. However, Japan has yet to develop a comprehensive legal and policy framework specifically for the protection of UCH. In particular, the Japanese government does not appear to have a clear or unified policy regarding the treatment of Second World War shipwrecks – an issue that remains sensitive due to complex historical and political factors.

Across the Pacific and Southeast Asia, an estimated 3,800 Second World War-era shipwrecks lie on the ocean floor, including approximately 3,000 Japanese military and merchant vessels. These sunken relics now pose potential environmental threats. Moreover, they have become targets for illegal salvage operations, heightening the risk of structural damage and environmental contamination.

Notable cases include the *Haguro*, *Chosa Maru*, and *Kuma*, which were salvaged off the coast of Penang, Malaysia. In response to such incidents, the Japanese government did not assert any claims. This lack of protest may be interpreted by other states as acquiescence, thereby contributing to the formation of customary state practice.

Japan tends to adopt a case-by-case approach to management of Second World War shipwrecks. Typically, the government responds to illegal salvage and oil leaks through diplomatic channels and collaboration with local authorities and experts. This passive posture may be partly explained by the fact that, after the formal resolution of wartime compensation and property claims with affected countries, sunken Japanese warships were eventually registered as state-owned property under the Ministry of Finance. However, while such registration formally establishes ownership, the Ministry regards it merely as a basis for potential management rights and does not bear responsibility for environmental protection or cultural preservation.

To date, the only clearly articulated Japanese policy in this area pertains to the recovery and repatriation of human remains from the Second World War under the 2016 Act on Promotion of the Collection of Remains of the War Dead. This initiative is regarded as both a humanitarian obligation and a national duty, with a particular focus on overseas battlefields.

In the context of the UN Decade of Ocean Science for Sustainable Development and the growing international emphasis on preserving historical and cultural heritage, there is hope that Japan will embrace cooperation in establishing international standards and a clear, comprehensive domestic policy. This will require cross-sectoral coordination among relevant ministries, strengthened international cooperation and legislation, as well as proactive measures to prevent illegal salvage and mitigate the serious environmental risks posed by sunken Second World War vessels. At the same time, these wrecks should be preserved as sites of cultural and historical importance and respectfully commemorated as war graves.

FOCUS ON

Arctic legacy of war – the *Tirpitz* salvage site

Dr Bryan Lintott
Scott Polar Research Institute, University of Cambridge

Despite its remote location, the Arctic bears the environmental and communal scars of the Second World War. One significant example is the salvage site of the German battleship *Tirpitz*, sunk by the Royal Air Force in 1944 near Tromsø, Norway. *Tirpitz* and its sister ship, *Bismarck*, were the Third Reich's largest and most powerful battleships, posing a severe threat to Allied Arctic convoys supplying the USSR. After its sinking, salvage operations removed high-quality steel and operational equipment, but hundreds of cubic meters of debris and contaminants, including hydrocarbons, printed circuit boards, heavy metals and small calibre ammunition were left behind on the seabed, creating long-term environmental risks.

The Tirpitz Site Project, a multidisciplinary initiative led by UiT The Arctic University of Norway and the Scott Polar Research Institute at the University of Cambridge, investigated the site using innovative technologies. In 2023, researchers produced the first detailed salvage area map, covering over seven hectares, using aerial-based through-water remote sensing. This method combined hundreds of images taken by airborne robots equipped with RGB and multispectral cameras to create a high-resolution map. The survey revealed debris piles with an estimated volume of 750m³ and a total mass exceeding 2,500 tonnes. Underwater robots were deployed to identify specific debris, including boiler tubes, while structure-from-motion 3D modelling provided further insights into the site's debris piles and scattered objects.

The environmental risks posed by the Tirpitz Site are significant. Contaminants from the wreck threaten marine ecosystems, including fish stocks and shellfish populations which are vital to local communities. These risks are compounded by the lack of environmental controls during post-war salvage efforts, when materials were indiscriminately dumped on the seabed.

The Tirpitz Site Project highlights the complexity of managing legacy wrecks and integrating science, technology, archaeology and historical research to address these challenges. Public engagement has been a key aspect of the project, with recreational divers and the local Tromsø community contributing valuable information about the site's evolution over the decades.

The *Tirpitz* salvage site exemplifies the broader challenges of dealing with wartime wrecks. As heavy fuel oil embedded in the seabed and corroded munitions release toxins, the risks to marine ecosystems grow. The innovative mapping techniques developed through the Tirpitz Site Project are valuable for addressing similar issues globally, advancing vital efforts to locate monitor and remediate the toxic legacy of war.

7 What do solutions look like?

The Project Tangaroa workshop programme provided much evidence of the scale of the PPW challenge. It also showed that, even between the initiation of the programme and the final workshop, promising developments in policy and practice could be identified. The following expert contributions illustrate the calibre of the expertise engaged in this work. They also show that clear research agendas and priorities for action are crystallising that will create the momentum that is critical to the high-ambition pathways we need to follow.

7.1 Recognition of PPWs as a risk factor in blue investments

Aggregation of the necessary resources for comprehensive management of PPWs cannot happen overnight. However, by integrating PPWs into risk assessments and management plans for protected areas such as MPAs, management activity can be increased relatively quickly.

FOCUS ON

PPWs and their impact on blue carbon investments

Joao Sousa
Senior Programme Manager, International Union for the Conservation of Nature

Substantial investment is required to create clean, safe oceans. Greatly increased financial support is also critical to creation of thriving, resilient coastal communities. However, the damage to environment and livelihoods caused by oil spills from PPWs puts at risk the capital already committed to such efforts. It also threatens to raise critical red flags for investors focusing on sustainable marine investments and habitat restoration; blue carbon ecosystems, such as mangroves, seagrasses and salt marshes, utilise carbon sequestration to mitigate climate change while supporting biodiversity and local livelihoods. When oil spills occur the impacts are profound.

To safeguard blue carbon investments against the risks posed by PPWs, a multi-faceted approach is essential:

- Initiate pre-emptive risk assessments and monitoring, and long-term management. Regular monitoring in ecologically sensitive areas can serve as an early warning system, enabling timely interventions when necessary.
- Design regional intergovernmental led remediation and restoration plans, establishing protocols for the rapid remediation of oil spills or hazardous material leaks that may also include assistance from engaging marine conservation organisations and thus empowering or leveraging existing national frameworks to respond to these threats.
- Investing in research of the environmental and socioeconomic impacts of PPWs on blue carbon systems will inform better investments. Knowledge sharing among stakeholders will facilitate a collaborative effort to identify high-risk areas and prioritise protective measures.
- Developing insurance and financial instruments (such as parametric insurance, that covers the probability of a loss-causing event instead of indemnifying the actual loss incurred from the event) tailored for blue carbon investments that consider risks from PPWs. This encourages investor confidence and promotes sustained investment in blue carbon projects.
- Advocating for new policies and law for more sustainable management of PPWs. Collaborating with government regulatory agencies to establish preventive measures and response protocols will foster a more secure investment landscape.

Proactive measures will mitigate the impact of PPWs on blue carbon investments and safeguard ecological and economic investments. Protecting blue carbon ecosystems is a good stewardship path for sustainable development, climate resilience, with ecological benefits and economic returns.

7.2 Multi-disciplinary science: what would a PPW programme look like?

If PPWs are to be included in risk assessments and MPA management, then a sound understanding of impacts and options for mitigation is needed – this must include the ability to factor-in the complex interaction of natural and cultural heritage.

FOCUS ON

Maritime heritage ecology

Dr Kirstin Meyer-Kaiser, Dr Colleen Hansel, Dr Calvin Mires, Dr Jared Goldstone, Dr Maria Pachiadaki, Dr Christopher Reddy, and Dr Dwight Coleman
Shipwrecks and Beyond Team, Woods Hole Oceanographic Institution

There is currently a significant deficit in scientific knowledge to support evidence-led PPW management, for example in the context of existing or proposed MPAs. Large knowledge gaps regarding their environmental contexts remain, and our ability to fully reflect the complex interaction between flora and fauna and PPWs in marine ecosystems is limited.

The Shipwrecks and Beyond Team at WHOI has spearheaded work that has shown how changes to the physical structure of a shipwreck shape its surrounding biological community.[61 62 63] The team plan to further explore the complex interplay between physical, chemical, and biological processes impacting PPWs over time. Specifically, to understand:

- How microorganisms influence the corrosion rate of shipwrecks, and how this is affected by water temperature, acidity, and the presence of oil.
- To what extent 'encrustation' by larger calcifying organisms slows or stops the corrosion of shipwrecks, and how this is also affected by temperature, acidity and oil.
- How organisms affected by leaking oil or dissolved trace metals from PPWs adapt, and how the chemicals released impact the broader ocean environment.

Microorganisms play a crucial role in the transformation of metallic underwater structures, primarily through biocorrosion. Sulphate-reducing, iron-oxidizing and iron-reducing microorganisms that are enriched in shipwrecks accelerate metal degradation by forming biofilms that alter local chemical conditions.[64 65 66] They facilitate electrochemical reactions, produce corrosive byproducts, and deposit metal oxides, leading to structural weakening.

Shipwrecks affected by the *Deepwater Horizon* oil spill had faster rates of corrosion than unaffected shipwrecks,[67] suggesting that biocorrosion may be influenced by the presence of oil. Climate-driven changes to water temperature and acidity could also influence the corrosion rate, but these processes have rarely been investigated.[68]

For larger organisms, including invertebrates, the physical structure of the animal might play a role in halting corrosion. Calcium carbonate deposits called 'encrustations' created by these organisms can protect underwater archaeological artifacts and structures.[69] Upon recovery, many artifacts are covered in a calcified layer, and degradation of the artifact increases when the encrustation is removed.[70]

It is unclear whether encrustation is a biological or chemical process, but biological encrustations in the form of calcifying organisms have been found on ancient artifacts and have aided in their preservation over centuries underwater.[71] They may therefore also help protect PPWs. However, reef-building corals are adversely affected by rising global temperatures and ocean acidification, which lead to coral bleaching.[72] Oil leaking from PPWs could result in further harm to coral encrustations.

The sinking of a vessel to the seafloor introduces chemical compounds that do not occur naturally or would not be present at elevated concentrations. These compounds, including trace metals and hydrocarbons, could create chronic stressors that drive acclimation or adaptation of surrounding fauna. Previous studies have shown dramatic changes in biological community structures surrounding shipwrecks.[73] [74] However, impacts on individual organisms and their potential for adaptation are much less understood. There may be certain thresholds in oil concentration that affect organisms, or 'tipping points' that drive mass mortality; however, the nature and magnitude of these effects are completely unknown.

The ecological effects of oil leaks from PPWs are extremely context-dependent, with the scale of impact determined by the type of oil and rate of release. Organisms that are already chronically stressed may be more sensitive to mortality. The oceanographic context, particularly circulation patterns, wind, and wave action, influence how oil is dispersed,[75] with the impact varying based on seasonal weather, tidal cycle, and human activities.

Answering the research questions described above will provide the foundation for future PPW risk assessments that incorporate ecological factors in a nuanced, context-dependent manner, enabling integrated management of UCH and evidence-led due diligence prior to investment in marine infrastructure. Corrosion rates and probability of oil release will be predicted with more accuracy; interdependence with colonizing fauna will be better understood; and knowledge on the toxicological impact of PPWs will aid prioritisation and remediation plans. However, every PPW is different, so research must be conducted on PPWs of interest in situ for refined understanding of their particular environmental risks.

7.3 Regional modelling of PPW deterioration

PPWs are a global problem that need to be understood in their regional and local context. Developing the capacity to model PPW deterioration on a regional scale is at the heart of ongoing research at the National Museum of Denmark.

FOCUS ON

ENDURE – corrosion, risk, and the science of safeguarding historic wrecks

Prof David Gregory
Research Professor, Environmental Archaeology and Materials Science, National Museum of Denmark

The ENDURE project is an interdisciplinary research initiative dedicated to developing a scientific framework for assessing the preservation and environmental risk of UCH. A key component of this effort is understanding how metal shipwrecks deteriorate – particularly in the North Sea and Baltic Sea.

ENDURE investigates where and how corrosion occurs, and what factors influence the vulnerability of these wrecks. To that end, it explores the role of ship type, construction form, and original function in shaping corrosion patterns. For instance, warships often use dense structural steel and have compartmentalised hulls, which corrode differently than the open holds of cargo vessels or smaller fishing boats. Internal factors such as ballast, bilge design, fuel tank configuration and cargo residues all contribute to creating distinct microenvironments that accelerate or inhibit corrosion.

The project combines legacy data, controlled laboratory experimentation and in-situ corrosion monitoring. Metal test samples are deployed at selected wreck sites to measure degradation over time under varying environmental conditions – such as salinity, oxygenation, sediment type and biological activity. These field studies are complemented by laboratory analyses using scanning electron microscopy, X-ray diffraction and electrochemical impedance spectroscopy to characterise corrosion products and assess structural stability.

A novel aspect of ENDURE is its integration of molecular biological research. The project uses DNA sequencing and microbial community profiling to examine how microbial populations – especially sulphate-reducing bacteria – contribute to or inhibit corrosion. This microbial influence is particularly significant in low-oxygen and anoxic environments, where biological activity can dramatically affect corrosion dynamics.

All findings feed into the development of entropy-based predictive models that estimate both preservation potential and environmental risk. These models synthesise biological, chemical, and physical data – drawing also from decades of legacy wreck surveys – to identify which sites are most at risk of structural failure and pollutant release.

By bringing together corrosion science, environmental microbiology, marine engineering and heritage policy, ENDURE offers a comprehensive and forward-looking approach to managing submerged wrecks – bridging the gap between cultural preservation and environmental protection.

7.4 Satellite data: a key tool

Large advances have been made in acquisition and use of satellite data – including extensive use of archive material to produce time-series coverage. What are the priority actions to maximise benefits for PPW management?

FOCUS ON

Project Tangaroa Satellite Working Group – a call to action

Convener: ***Dr Michael L. Brennan,*** *SEARCH/Brennan Exploration*
Members: ***Dr Elizabeth C. Atwood,*** *Plymouth Marine Laboratory;* ***William Jeffery,*** *Viridien Group;* ***Mathew Skelhorn*** *and* ***Harriet Rushton,*** *Salvage and Marine Operations (SALMO), UK Ministry of Defence;* ***Freya Goodsir*** *and* ***Hayden Close,*** *Centre for Environment, Fisheries and Aquaculture Science.*

Many types of oil are lighter than water and therefore, when introduced to the ocean, create slicks on the sea surface. These can be detected by satellites with synthetic-aperture radar by day or night, provided wind speeds are within a certain range.[76]

Optical sensors are better at detecting oil, but limited to daylight hours and by cloud cover. By analysing the imagery over time to track the movement of oil slicks, leaking wrecks on the seabed can be located. Satellite detection is a proven, cost-effective tool to detect and monitor PPWs. It can enable rapid location and wide area monitoring, and provide early warning of pollution events. This is especially useful given the exact locations of many PPWs are unknown, and their pollution risk is therefore unassessed.

Satellite oil detection was successfully used in 2021 to find the wreck of the oil tanker SS *Bloody Marsh*, sunk by a U-boat in 1943 off the coast of South Carolina at a depth of 465m. More than 20 leaking wrecks have also been identified using the EU Copernicus programme satellites Sentinel-1 and Sentinel-2.[77]

Some oil leaks from PPWs have been caused by human interference. According to recreational diver reports, the HMS *Prince of Wales* and HMS *Repulse* leaked small amounts of oil for years. However, satellite surveillance showed that significant leaks, from 2013 onwards, were entirely the result of illegal salvage (see page 38) – demonstrating that satellite imagery can also be used to detect increased leak frequency and severity (figure 12).

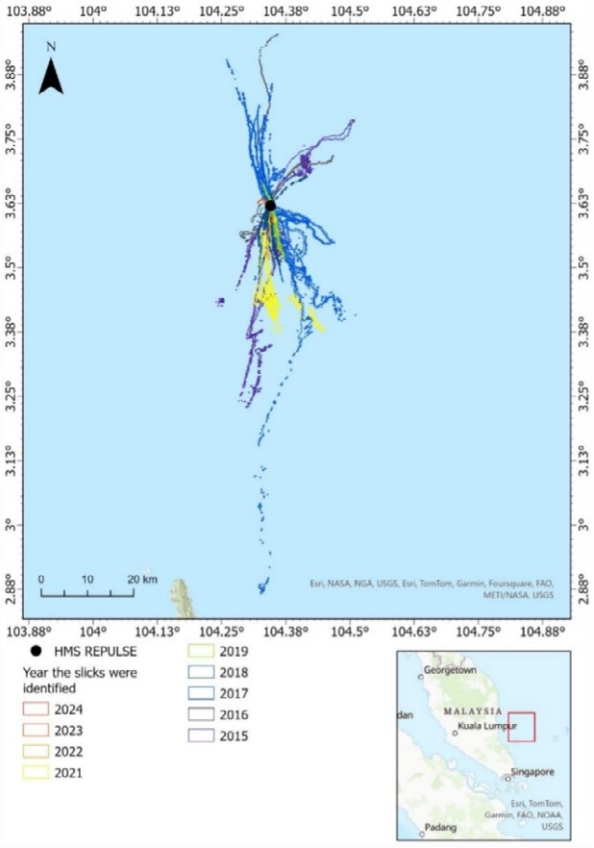

Figure 12: Leaks detected and delineated as part of a study on satellite wreck monitoring (Close et al., forthcoming).

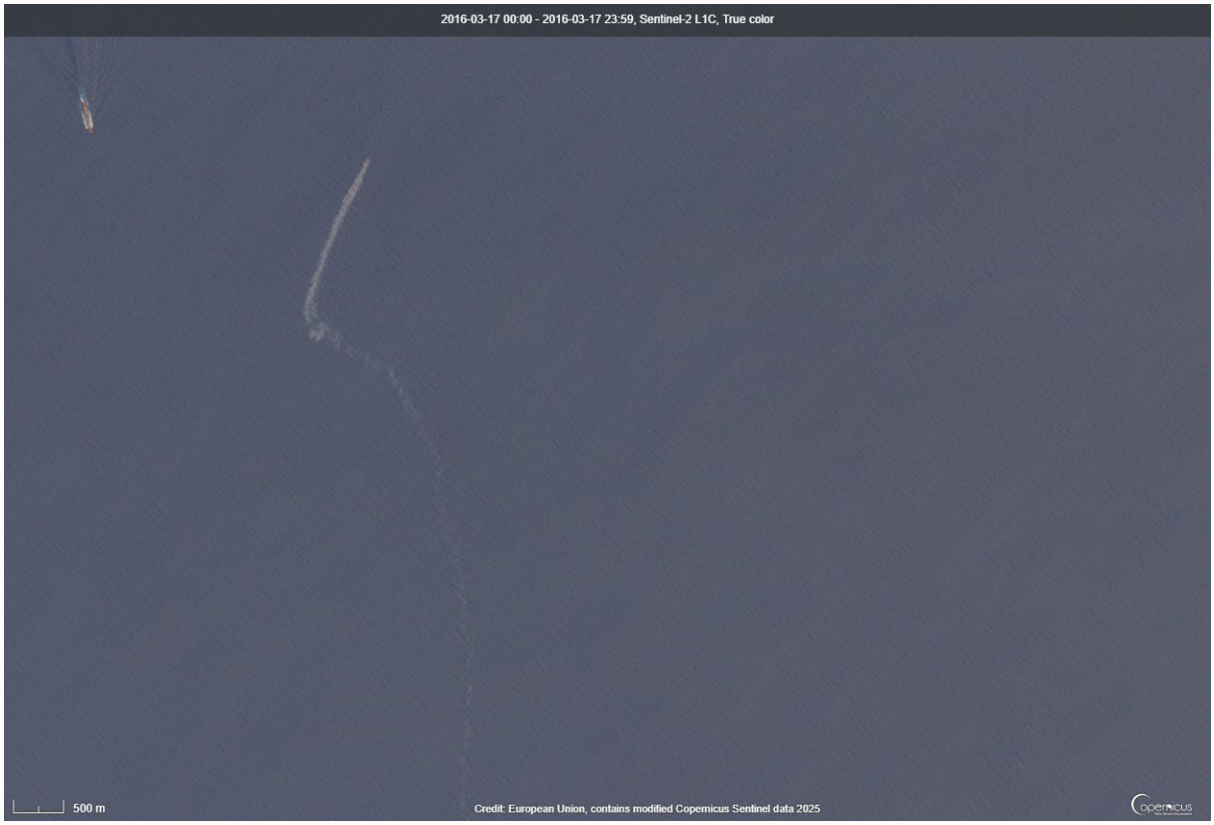

Figure 13: oil leaking from HMS *Repulse*, as seen from an optical satellite.

To unlock the full potential of satellite surveillance, we must prioritise changes in data collection and access to ensure open and widespread availability of these critical images:

- More open access to satellite data for oil detection is needed. A number of international companies and research entities collect, process, analyse and archive satellite imagery, with extensive databases going back decades. Some repeating oil slicks have come to researchers' attention, but many likely remain unobserved. There must be specific support for these satellite imagery companies to provide full public or researcher access to query their imagery datasets. Once identified through satellite imagery, the slick location can be cross referenced with reported ship sinkings, and surveys to precisely locate and assess the wreck can be initiated.
- Government operated earth-observation initiatives (such as Copernicus and Landsat) should extend satellite acquisition plans (especially synthetic-aperture radar imagery) over regions currently not within the regular monitoring programmes (e.g. the Coral Sea). A paucity of data over many Second World War battle regions currently precludes PPW monitoring. With relatively minor adjustments to imagery schedules, these areas could be covered.
- An extensive intelligence-led operation should be supported to optimise satellite surveillance as a tool to combat illegal salvage and control associated pollution risk. This could include the integration of AI tools to automatically detect slicks from actively polluting wrecks.

7.5 Alignment with ocean governance and underwater cultural heritage policy developments

There is increasing recognition that safety threats like PPWs need to be managed as one element within increasingly complex and stressed maritime and ocean systems. There is currently a window of opportunity to engage with broader ocean stewardship programmes to develop lasting and durable solutions.

FOCUS ON

Integrating PPW management within broader policy frameworks

Ole Varmer
Senior Advisor, The Ocean Foundation

Project Tangaroa's vision, as outlined in the Malta Manifesto, is based on international collaboration to implement a precautionary approach to management of PPWs. Nations should voluntarily implement their duty to protect the marine environment and the PPWs that are historic objects, if not UCH, under customary international law, as reflected in UNCLOS which provides the framework for any next steps to safeguard our ocean heritage.

Numerous existing laws could be implemented to achieve this vision. In implementing the recent treaty to protect biodiversity in areas beyond national jurisdiction (BBNJ), nations should collaborate to ensure that PPWs and cultural heritage are included in the management of the resources of these areas and the high seas through environmental impact assessments (EIAs) and area-based management tools, especially MPAs.

At the International Seabed Authority (ISA), many nations and NGOs, including The Ocean Foundation, are advocating for a temporary moratorium on deep-sea mining until cultural heritage is incorporated into the regulations (among other concerns).

However, as noted by Duncan Currie in a forthcoming book on deep-sea mining, "protecting UCH under the BBNJ Agreement is likely to involve extensive consultation with both the ISA and UNESCO. Cultural matters, as well as traditional knowledge, are specifically included in both the area-based management tools and the EIA parts of the BBNJ Agreement, and are also likely to arise in other contexts, including capacity building and the transfer of marine technology. Once BBNJ enters into force, international cooperation provisions, including the ISA where activities in the area are concerned and UNESCO when underwater cultural heritage or intangible cultural heritage is concerned, will be important in resolving issues".[78]

Integrating PPWs into deep-sea mining licensing and management via EIAs is critical and risk analysis should extend to considering the potential impact of bottom trawling on PPW integrity and stability. Thus, EIAs should be conducted and significant natural and cultural heritage in the area designated as no mining and no trawling zones, being instead considered as marine protected areas. These are crucial issues for consideration by nations in these forums and other relevant UN entities.

7.6 A PPW technology research and development roadmap

A 'roadmap' will provide the foundations for a research and development strategy for PPW assessment, intervention and management, aligned to the 2039 target set by the Malta Manifesto. We need to reduce costs, increase access to data, and deliver safe, sustainable options for intervention. There are significant opportunities for technological innovation to enable this.

A research and development roadmap for potentially polluting wrecks (PPWs)

COLLECTING MORE OF THE DATA WE NEED, AT LOW COST

Satellite surveillance: Satellite data is a vital tool for early warning of spills and wreck location and monitoring. We must find ways to achieve satellite coverage of key regionals at lower cost.

Autonomous Underwater Vehicles (AUVs): We must revolutionise the economics of finding and monitoring PPWs. AUVs could be platforms for a wide array of this data collection, but innovation is needed to enable new models of 'real-time' monitoring of large sea areas.

Oil detection: It is always difficult to assess the amount of oil in a PPW – this inhibits planning and can create unnecessary cost. Neutron back-scatter and acoustic resonance technology may offer opportunities to make this critical process more efficient and reliable

TURNING DATA INTO ACTIONABLE INSIGHTS AND INFORMATION QUICKLY

Artificial Intelligence (AI): We must make better use of expanding AI capabilities. Opportunities for AI application include more efficiently matching seabed structures with archival material, analysing masses of satellite data to quickly spot and track spills, and assimilating masses of structured and unstructured data for impact monitoring.

END TO END OPTIMISATION OF ENGINEERING INTERVENTIONS

Oil removal: Developing and scaling oil removal technology for a wider range of PPW scenarios is critical to managing these wrecks. We need new techniques for use on fragile structures; this may include a role for biological remediation (using oil-eating enzymes).

Oil transport, storage and recycling: When oil is removed from a PPW, it is normally pumped to a waiting vessel, for transportation to and/or storage in a suitable facility where it can be processed. We must create a sustainable, end-to-end process for this, with a lower carbon footprint, especially in remote locations.

Workforce safety: throughout, we must improve access to evidence on 'what works' in occupational safety for the PPW workforce, and implement trackable skills training and safety assurance methodologies.

8 Recommendations

8.1 Summary of recommendations

All of the below recommendations must be collectively implemented through the drive and influence of a range of stakeholders working across the maritime system and beyond. It is also recommended that key actions aligned with advocacy, convening, standards and fundraising should be given additional catalytic support by a dedicated secretariat, such as Project Tangaroa.

For implementation by PPW stakeholders, actively supported by a secretariat:

1. An advocacy campaign should be coordinated to secure urgent action and lasting change.
2. International standards for PPW management should be formulated and disseminated through the IMO.
3. UNEP and UNESCO should be engaged in discussion on development of PPW guidelines and toolkits and integration of PPWs into relevant international policy frameworks. These discussions should seek explicit acknowledgement of PPW management as an important action aligned with Sustainable Development Goal 14 and its aim to avoid and dramatically decrease marine pollution.
4. A PPW finance task force should be established to lead a campaign to ensure that fit for purpose finance is mobilised at scale to protect vulnerable communities and the environment.
5. A technology roadmap should be developed to chart the path to the democratisation of scaled technology.
6. A PPW data access and archive strategy should be developed to maximise availability of information that enables evidence-led PPW management.

For implementation by PPW stakeholders:

7. Stakeholders should commit to localisation and empowerment to ensure that those most affected have the strongest voice in finding safe solutions.
8. Climate change impacts and illegal salvage should be acknowledged as severe risks to PPW stability and opportunities should be sought to address this through relevant national and international policy development.
9. PPWs should be explicitly included in national and regional oil spill response strategies.
10. PPW management should be integrated into broader ocean stewardship, coastal management and marine spatial planning frameworks, associated risk assessments and related policy development.
11. PPWs should be recognised and assessed as a risk-factor potentially requiring mitigation in connection with matters such as blue investments, habitat restoration projects and planning and management of marine protected areas and highly protected marine areas.
12. The data required to implement such risk assessments, associated mitigation strategies and management plans should be evaluated and necessary research initiated urgently to address any key gaps.
13. PPW management workforce safety should be assured across all sectors and activities.
14. PPW management must be integrated with broader efforts aimed at addressing the complex and toxic legacy of war.

For Lloyd's Register Foundation:

Building on the above recommendations, Lloyd's Register Foundation is uniquely placed to make an impact in the following ways:

- **Supporting a central secretariat:** Key to success is the convening of Project Tangaroa stakeholders to form a secretariat for the next phase of the work. The Foundation is uniquely placed to support the initial establishment of this secretariat. The secretariat will need to become self-supporting, and a fundraising element to its work will help ensure its longevity and sustainability.
- **Through archives and heritage:** Evidence-led PPW management, as highlighted in recommendation 6, is essential, with significant amounts of data and open-access archives needed. The Foundation should make its archive as accessible and useful for PPW research as possible by continuing its programme of digitising classification records, further opening access to key technical information. The Foundation is well placed to lead efforts in the heritage sector that advocate for the use of historical information to address present day safety challenges such as PPWs – learning from the past for safer maritime systems.
- **Skills and education**: The creation of new standards by the IMO, as highlighted in recommendation 2, will require targeted research and skills development to adopt and enforce them locally. The Foundation can support this capacity building by building on existing grants to support studentships at the IMO International Maritime Law Institute, through which the next generation of maritime law specialists can be equipped to effectively navigate the legal frameworks concerning PPWs. Priority should be given to geographical areas where more skills and training are required. This will further support vulnerable communities, regional strategies and the creation of international standards and improved legal frameworks for PPW management.

  In relation to recommendation 13 on PPW workforce safety, there is scope for a piece of work focussed on evidence gathering and mapping of what skills are needed where. This work would identify who the PPW management workforce are, where there are gaps, and what skills are needed to ensure this work is done safely. There would be a focus throughout on enhancing safety culture and safety leadership. Such work aligns with existing Foundation activity including the 'Skills for Safety' partnership with Engineering X. The Foundation could be well placed to create a global understanding of skills needed for PPW management.

8.2 Recommendations in detail

1. An advocacy campaign should be coordinated to secure urgent action and lasting change.

This report highlights the serious risk posed by PPWs. It also identifies examples of positive developments in their management. However, in many cases, such progress is fragile and dependent on short-term funding cycles, or relies on voluntary contributions or philanthropy for resources. It is rarely funded through statutory means and lacks the durable obligations necessary to withstand future reductions in commitment. A strong advocacy campaign is crucial for achieving a lasting resolution to the PPW threat based on long-term commitment. This campaign should amplify the call for urgent and ambitious action made in the Malta Manifesto.

Key messages in communications should include:

- Protection of some of our most vulnerable communities requires proactive intervention supported by international collaboration and multilateral finance.
- A strategic approach is fundamental to the most economic and efficient use of resources.
- Assessment of vulnerability should be a primary driver in decision-making.
- Integrated care for natural and cultural heritage is critical and indivisible as we strive for safe and healthy ocean systems.
- Respect for the human remains likely present on many PPWs, some of which are considered as war graves or maritime memorials.

2. International standards for PPW management should be formulated and disseminated through the IMO;

3. UNEP and UNESCO should be engaged in discussion on development of PPW guidelines and toolkits and integration of PPWs into relevant international policy frameworks. These discussions should seek explicit acknowledgement of PPW management as an important action aligned with Sustainable Development Goal 14 and its aim to avoid and dramatically decrease marine pollution.

Increased national and multilateral finance is needed for prevention of large spills from PPWs worldwide. Acknowledgment at the state level of international standards that guide the assessment and management of PPWs will make provision of such finance more likely; such standards will offer clarity and assurance to a wide range of stakeholders and policymakers and increase confidence in the commitment of resources. The standards should be designed to optimise cooperation between the flag states of PPWs and the coastal states where they are located.

Formulation and dissemination of such standards should be achieved through formal engagement with the IMO in the first instance. Appendix 3 sets out a proposed road map.

Following the launch of the Malta Manifesto, there is clear evidence that UNEP and UNESCO will welcome engagement on the PPW issue. The welcome given to the IUCN-ICOMOS Joint Statement (Appendix 2) signals that the need to treat culture and nature as indivisible in PPW management is recognised.

4. A PPW finance task force should be established to lead a campaign to ensure that fit for purpose finance is mobilised at scale to protect vulnerable communities and nature.

International cooperation is central to funding the management of PPWs.

In some of the regions where the PPW threat is highest and resilience is at a relatively low level, national resources are not adequate to protect communities and nature. Further, coastal states in these regions played no role in the creation of this threat to livelihoods and ocean health. They cannot be expected to meet these costs alone. The moral case for multilateral support and collaboration is overwhelming. Key tasks include development of diversified financial support mechanisms, alignment of multilateral and regional funding and development of emergency response support for PPWs. It is certain that considerable innovation will be required in the design and implementation of such finance solutions.

Given this urgency and complexity, a PPW finance task force is needed to show leadership, convene decision makers and marshal specialist expertise to develop and implement funding solutions at the required speed and scale.

5. A technology roadmap should be developed to chart the path to making scaled technology widely available and affordable.

Government agencies, the research community, and the marine services and engineering sector possess a diverse range of capabilities for locating, assessing, and managing PPWs. However, to scale up PPW management rapidly, the cost base for such work must be reduced dramatically. While innovation in technology and methodology will certainly be a core component of scaled PPW management efforts, cost-efficiency can also be achieved through multi-PPW survey campaigns as opposed to single site activity. In addition, a commitment to localisation requires greater access to easily deployable capabilities for data collection, monitoring, and analysis. Development of a technology roadmap will identify critical areas for early development that will facilitate cost-efficient operations at scale, including:

- Satellite surveillance and data: an essential technology in the development of wide area monitoring and early warning of spills.
- AI: offers the potential for near-real-time monitoring of data and the creation of actionable insights from diverse and unstructured data sources.
- Autonomous vehicles and ubiquitous sensors: enabling active monitoring.
- Enhanced, non-intrusive methods for assessment of residual oil.

6. A PPW data access and archive strategy should be developed to maximise availability of information that enables evidence-led PPW management.

A data and archive strategy for PPWs must address multiple aspects of data adequacy and data access to enable optimised decision making and support advocacy. Several recent initiatives focused on different sectors (including heritage, ocean sciences and data collected in advance of marine development) have resulted in meta-data portals and commitments to enhanced access to information. These can be built upon to democratise creation of knowledge and insight. The PPW data access and archive strategy should make the case for maximum possible open access to material. Examples of issues include:

- The need for better characterisation of the overall PPW inventory.
- A need for better baseline data and monitoring.
- Curation of time-series datasets.
- Enhanced online access to digitised archive materials.
- Leveraging data creation by 'vessels of opportunity' deployed for other primary purposes, such as foundation-run research vessels and fishing boats.

7. Stakeholders should commit to localisation and empowerment to ensure that those most affected have the strongest voice in finding safe solutions.

PPWs are a global issue with potentially catastrophic impacts at the local level. So, the specific circumstances in each region and location must be carefully considered to develop safe and effective management strategies. Moreover, while technical and economic constraints on available management options are inevitable, the views and wishes of affected communities should be given significant weight in the decision-making process. A commitment to project co-design, localised protocols and empowerment of communities through provision of resources and knowledge transfer is central to achieving equitable and sustainable solutions.

8. Climate change impacts and illegal salvage should be acknowledged as severe risks to PPW stability and opportunities should be sought to address this through relevant national and international policy development.

While the likely rate of dilapidation of PPWs can be modelled and management plans developed accordingly, two factors have been shown to be capable of causing greatly accelerated collapse of structural integrity and increased risk of major pollution. Climate change impacts, such as more powerful typhoon seasons, storm surges and warming waters leading to increased acidification, are dramatically accelerating the deterioration of PPWs. The UNESCO White Paper, *Underwater cultural heritage, climate change: adaptation and mitigation* (UCH/25/10.MSP/5.INF) provides an important framework for consideration of climate impacts and better integration of cultural heritage into existing national and international frameworks for mitigation and adaptation.

Significant pollution events have already been caused by looting and illicit salvage of PPWs for commercial and potentially geopolitical motives. This can occur beyond the territorial waters of a coastal state and yet still cause severe harm to that state. PPWs should be addressed in current discussions about extending stewardship efforts beyond current boundaries of national jurisdiction, such as the regulation of mining at the ISA and implementing the recent treaty on protecting BBNJ.

9. PPWs should be explicitly included in national and regional oil spill response strategies.

There is mounting evidence that major incidents around the world are inevitable if no action is taken on PPWs. In addition to the risk of environmental harm, certain regions have economies, such as fishing and tourism, that are hyper-sensitive to even small amounts of oil, yet readiness levels to respond to spills remain relatively low. Therefore, it is essential that existing operational provisions for emergency spill response be adapted and applied quickly to address PPW-sourced pollution. Longer-term management plans to minimise or prevent disasters from PPWs should also be developed.

10. PPW management should be integrated into broader ocean stewardship, coastal management and marine spatial planning frameworks, associated risk assessments and related policy development;

11. PPWs should be recognised and assessed as a risk-factor potentially requiring mitigation in connection with matters such as blue investments, habitat restoration projects and planning and management of marine protected areas;

12. The data required to implement such risk assessments, associated mitigation strategies and management plans should be evaluated and necessary research initiated urgently to address any key gaps.

It is essential that the significance of UCH, in both tangible and intangible forms, is better understood by the ocean stewardship community. PPWs are part of that heritage advocacy. However, they also require particular recognition as a potentially potent risk factor in the context of investment in ocean health and communities.

Investments in our ocean take a number of forms. A wide variety of commercial development proposals require formal environmental and impact assessments. Investments directed specifically at ocean stewardship, such as habitat restoration projects, are generally preceded by comprehensive due diligence checks to ensure capital is not unduly put at risk. Resources are also invested in planning and management of protected areas such as marine protected areas. PPWs represent a material risk to all such investment yet are rarely adequately considered; PPW management should be included in the formal due diligence, environmental assessment and mitigation processes associated with ocean investment.

To enable consideration of PPWs as a risk factor, it is essential that the fundamental requirements for science-based decision making in relation to PPW management are established and codified. A review of existing scientific knowledge should include current availability of relevant baseline data, knowledge on meaningful thresholds of concern and criteria for environmental impact evaluation. A multi-disciplinary research programme should then be initiated to address key information gaps. An awareness raising campaign should be implemented to inform stakeholders of the role of techniques such spill modelling and satellite surveillance in the development of practical PPW management plans in the context of MPAs and other protected areas.

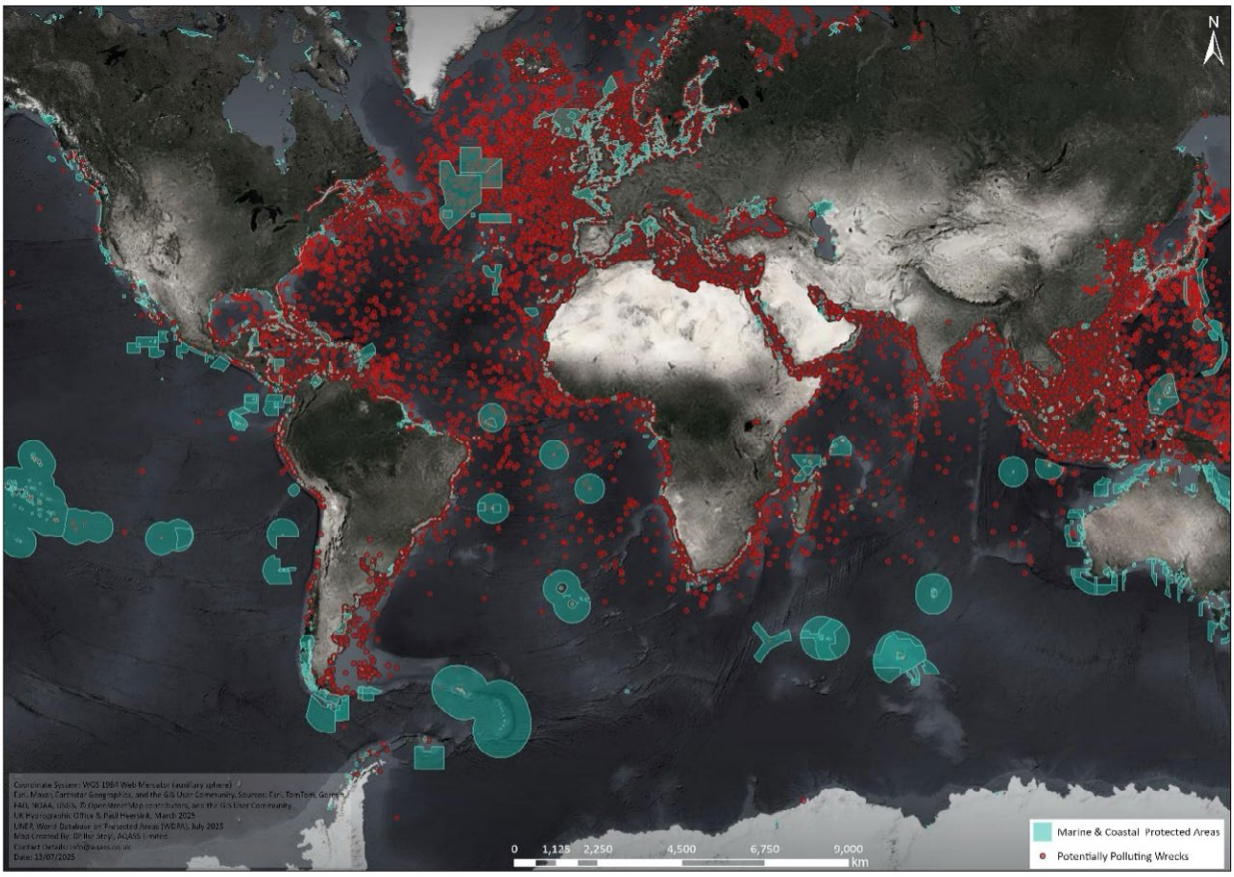

Figure 14: known PPW locations overlaid on Marine and Coastal Protected Areas, giving clear evidence PPWs must be a key element in MPA planning. Map created by Dr Ilse Steyl, AQASS Ltd.

13. PPW management workforce safety should be assured across all sectors and activities.

PPW management involves work in a range of environments. Often this is undertaken in settings where inherent risk should be mitigated by enforceable obligations regarding the health and safety of employees. Where activities involve workers on short-term contracts or volunteer efforts, equivalent protections are essential; such activity can range from locally recruited workers assisting with oil spill clean-up, to citizen scientists giving their time and skills to help with PPW threat management. Whether through full compliance with safety at work legislation or through risk assessment and safe work statements, it is essential that all members of the PPW workforce can do their work in safety and with access to appropriate training and equipment. For example, current best-practice should be built on and codified to establish a framework for assurance of the safety of citizen science divers working on PPWs. Commitments should go beyond compliance and support a culture that puts personnel safety first.

14. PPW management must be integrated with broader efforts aimed at addressing the complex and toxic legacy of war.

PPWs from the World Wars are only one part of the legacy of war. Toxicity from unexploded ordnances, munitions and other toxins poses a threat to life, property and the food chain. Dangerous wreck structures can compromise safe navigation, and the safety of the marine workforce is also at risk. Contemporary geopolitics – especially new tensions that often have their roots in past conflicts – may complicate PPW management efforts, and in some cases, are associated with illegal salvage or other forms of interference, leading to consequent pollution. There is also the human legacy of conflict – many PPWs contain human remains, and some are considered as war graves. Veterans and their relatives have a stake in the management of these sites. But the human legacy of war also encompasses the coastal communities that both endured conflict and now are threatened by its physical legacy in their waters; their perceptions and priorities regarding appropriate management options may not reflect the views of other countries.

9 Glossary of acronyms

All acronyms are explained within the text at the first point of use. Where abbreviations are used numerous times throughout the report, they are noted here for clarity.

AUV	Autonomous Underwater Vehicle
BBNJ	Marine Biodiversity of Areas Beyond National Jurisdiction
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
GIS	Geographic Information System
ICOMOS	International Council on Monuments and Sites
ICUCH	International Committee on the Underwater Cultural Heritage
IMO	International Maritime Organization
ISA	International Seabed Authority
IUCN	International Union for the Conservation of Nature
MoD	(UK) Ministry of Defence
MPA	Marine Protected Area
NOAA	(US) National Oceanic and Atmospheric Administration
PPW	Potentially Polluting Wreck
REMARCO	Remediation, Management, Monitoring and Cooperation addressing North Sea UXO
ROV	Remotely Operated Vehicle
UCH	Underwater Cultural Heritage
UNCLOS	The United Nations Convention on the Law of the Sea
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UXO	Unexploded Ordinance

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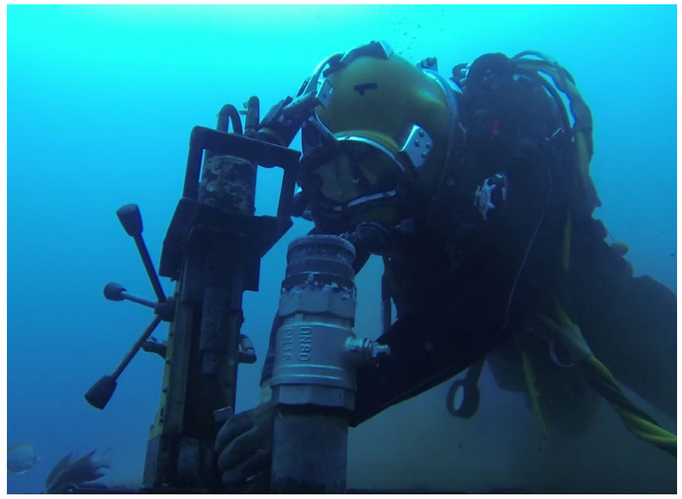
APPENDIX 1:

The SALMO Standard Operating Procedure

The below flowchart shows a simplified version of the wreck management plan (WMP) process followed within the standard operating procedure employed by the SALMO wreck management team at the UK MoD.

The highlighted path through the process shows how it was applied to the real-life wreck example of RFA **Darkdale**, a British tanker lying in the waters of the island of St Helena in the South Atlantic. Darkdale had been filled with around 8,000 tons of fuel oil before being sunk by a German U-boat in October 1941.



- Procedure for **high** and **medium** risk wrecks such as Darkdale
- Steps taken for Darkdale
- Procedure for **low** risk wrecks

1 **Wrecks assigned priority 1–4.**

Assigned priority 1.

2 Produce historic desk-based assessment (HDBA) for priority 1 and 2 wrecks.

This Darkdale issue arose before the UK MoD had started to commission HDBAs.

3 HDBA suggests wreck could have significant quantities of oil onboard and is at **medium** or **high** risk of releasing oil.

AND/OR

Another country flags a wreck as being problematic in their waters, or an authority formally flags a wreck in UK waters as being at risk of or already leaking oil, to the MoD. The wreck then becomes priority 1 irrespective of its previous priority.

Darkdale had a history of continual oil leaks since she was sunk in 1941. A large leak occurred in 2010 resulting in calls from St Helena's Governor and the Foreign and Commonwealth Office for the MoD to act, as the owner of the wreck.

3 HDBA suggests wreck is **low** risk:

Re-categorise as "assessed and lower risk than previously thought, based on data available. Not requiring immediate survey." in wreck database. This requires subject matter expert input.

Re-assess at a later date/ monitor changes if possible.

4 Survey required. Cefas may be tasked to produce a 'basic' spill model based on quantities of oil reported in the HDBA. This supports the survey requirement.

A survey was deemed necessary.

4 Wreck starts to leak and/ or a country or authority formally flags it to the MoD as a problem.

5 If funds are available and allocated by the MoD, survey the wreck using – for example – side scan sonar, multibeam echosounder, ROV camera, hull thickness measurements, photogrammetry and/or neutron backscatter (if oil detection is possible via this method). Survey may be conducted using in-house resources or contracted out. Ship plans and other archive resources such as survivor accounts are analysed and compared with the condition of the wreck as revealed by the survey.

Survey was within WMP budget. In 2012 a SALMO team supported by environmental scientists and RPS Group surveyed the wreck and the surrounding bay to assess its condition and the risk posed. An ROV survey and environmental sampling was carried out.

6 If survey reveals the amount of oil remaining poses a significant risk (as assessed by subject matter experts), Cefas are tasked to produce a full environmental desk-based assessment (EDBA). Cefas may also attend the survey, to conduct sampling.

Survey revealed the wreck lay in two parts. The bow was inverted but in very good condition; the stern lay on its port side and had suffered substantial torpedo damage. The bow section was estimated to contain 2,326-4,952m³ of oil (a more precise estimate wasn't possible due to constraints imposed by the location of the wreck and survey tools available).

Environmental study found generally low levels of hydrocarbon contamination in the water column. Sediment samples were comparatively more contaminated, and levels of hydrocarbon compounds exceeded EU quality standards (EQS). Fish/shellfish samples were mostly found to contain low-level hydrocarbon contamination, with around 10% exceeding EQS and so representing a health hazard if consumed.

The wreck continued to corrode, making oil release inevitable. Intervention was therefore deemed appropriate.

7 Cefas EDBA concludes **medium** or **high** overall risk, HDBA and survey also concludes significant risk. Remediation may be appropriate. Whether this is the best practicable environmental option (BPEO) depends on a variety of other factors, which require assessment by a subject matter expert. These include for example the state of corrosion and structural integrity of the wreck.

An EDBA was not deemed necessary, as the survey and environmental assessment results had already indicated that it was necessary to remove the oil.

7 Cefas EDBA concludes **low** overall risk, as do HDBA and survey. Remediation not appropriate.

8 If funds are available and allocated from the MoD, a contract is tendered, bid for, set and executed. Oil is removed, e.g. by hot tapping. An oil spill response vessel and team is on standby.

Around 1,700 m³ of oil was successfully removed via hot tapping.

8 Update wreck's priority if necessary. Re-assess at a later date/monitor changes if possible.

9 Recycle oil if possible.

Oil was sent to a refinery in South Africa.

10 Wreck priority updated to 'remediated' in the WMP database.

Darkdale has been updated to 'remediated' in the MoD wreck database.

APPENDIX 2:

IUCN-ICOMOS Joint Statement on PPWs

Originally published on 11 June 2025 at www.icomos.org/actualite/icomos-and-iucn-statement-on-potentially-polluting-wrecks.

More than 8,500 shipwrecks worldwide – most caused by 20th century conflict – containing an estimated 2.5-20 million tons of pollutants, serve as a stark reminder of the legacy of humanity's common past. They are often labelled ticking timebombs, especially given that the positions of many PPWs remain imprecise.

Physical, biological and chemical processes – exacerbated by climate change – are compromising the structural integrity of these shipwrecks, with some already known to be leaking contaminants into the natural environment. A sudden structural failure of one or more of these vessels, resulting in a major oil spill, would pose an existential environmental threat. The impacts can be local, through the potential destruction of a shipwreck's associated ecosystem, but may also result in significant damage to underwater cultural heritage values, and possibly disturb human remains.

Blue economies at risk

Tourism centred around natural heritage ecosystems and the cultural and historic values associated with shipwrecks constitute a key economic activity in many places. The consequences of such a sudden structural failure, coupled with the subsequent clean-up efforts or pre-emptive actions to mitigate contaminants, will deliver a significant economic shock to these and other blue economies such as artisanal fishing.

Preventative mitigation is more cost-effective

Oil pollution carries enormous human and environmental costs, in addition to the financial burden of clean-up operations. The preventative management of PPWs to avert oil spills carries a significant financial cost. This can range from non-intrusive monitoring, utilising new technology that provides innovative options for remote surveillance, to planned interventions for oil removal. However, every available metric and case study clearly demonstrates that the cost of emergency response and clean-up vastly exceeds that of strategic management. In addition, experience has shown that it is near impossible to avoid long-term harm. The full natural and cultural value of a polluted ecosystem may never be fully restored.

Considering this existential threat to the ocean's health, IUCN and ICOMOS encourage governments and their relevant agencies to monitor, assess, and continue to develop and share innovative tools and best practices for the strategic management of and, where feasible, the removal of pollutants from sunken ships.

Furthermore, IUCN and ICOMOS call on UNEP to explore collaboration with governments and their relevant agencies to develop guidelines or a toolkit for use in evaluating the threat of pollution from shipwrecks and identifying possible solutions, keeping in mind that many PPWs are, at the same time, maritime gravesites and underwater cultural heritage. This initiative will be in direct support of the number one challenge identified by the UN Decade of Ocean Science for Sustainable Development (2021-2030); understand and beat marine pollution. IUCN and ICOMOS stand ready to support UNEP in this effort.

APPENDIX 3:

IMO Engagement Roadmap

Project Tangaroa was established under the Lloyd's Register Foundation two-year grant to The Ocean Foundation, in partnership with Waves Group. The key aim was to develop a framework for international standards for states to use in their near- and long-term assessment of risks, interventions, and the development and sharing of data necessary for the management of PPWs.

Experts were convened through a three-workshop programme. A clear consensus emerged that the IMO is the most appropriate unit of the UN system to consider taking up the international standards to address threats from PPWs. Based on the precedent of the process that resulted in the IMO 2007 Nairobi International Convention on the Removal of Wrecks, the 1989 International Convention on Salvage, the IMO Legal Committee is the most appropriate forum to consider the development of international standards for member states to use in addressing the threats to the marine environment and corresponding adverse impacts on local communities. However, the Marine Environment Protection Committee would logically be involved, as may the Marine Safety Committee in the event that safe navigation of vessels needs to be considered. It is possible that an initial output may take the form of guidance in an IMO Circular in advance of development of a full set of standards.

The key first step in the IMO process is developing a global coalition of relevant IMO member states willing to champion or support the submission of a proposal to the next session of the Legal Committee (LEG 113). The coalition should include at least one PPW flag state (e.g. the UK) and one coastal or island state with PPWs in their waters (e.g. the Republic of the Marshall Islands). It may also include the IUCN, which is an NGO with consultative status at the IMO.

The elements of the proposal should include a summary of the threats, the data needed to address and manage the threats, including risk assessments, guidance on the alternative interventions or solutions, the need for funding, and the need for cooperation between flag States and coastal States in a manner consistent with international law, including UNCLOS and relevant provisions of the 2007 Nairobi Wreck Removal Convention.

As LEG 113 will most probably convene from 13 to 17 April 2026, the deadline for the submission of the proposal is 16 January 2026.

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